# A COMPARISON OF TWO BURSTING STRENGTH TESTERS FOR KNITTED FABRICS: A MINI-DIAPHRAGM VERSUS A MINI-PROBE TESTER

by

Elva June Nilsen

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
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# ABSTRACT

Bursting pressures for twenty knitted fabrics obtained using a Hoffman/Turner mini-probe tester and a mini-Mullen diaphragm tester are compared. The results indicate that the Mullen tester gives more precise results of greater magnitude than the Hoffman/Turner tester. Hoffman/Turner results are shown to be probe size dependent. Mullen results are shown to be independent of rate of testing. Evidence to show that bursting strength behavior may vary with knit type is presented. A conversion table for the estimation of results given by one tester based on the results of the other is presented. Practical considerations in the use of the two testers are discussed and suggestions are made of ways to facilitate Mullen testing.

# ACKNOWLEDGEMENTS

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# Chapter I

# INTRODUCTION

Strength testing is an important aspect of quality control of textile materials. In the knitted textile industry, strength is assessed through determination of the force or pressure required to distend a fabric to rupture when the force is applied at right angles to the fabric under specified conditions (ASTM, 1980a; ASTM, 1980b).

Two types of testers are widely used to evaluate the bursting strength of textile materials (1)diaphragm bursting testers such as the B.F. Perkins Mullen tester (ASTM, 1980a; CGSB, 1977b; ISO, 1974b; BSI, 1972) and (2)ball bursting testers such as the attachments for the Scott Tensile Tester and the Instron Tensile Tester (ASTM, 1980b; CGSB, 1977c; United States Federal Test Method Standard Number 191, Method 5120, 1968). While these two testers have proven satisfactory for the quality control testing of most knitted fabrics, they are unsuitable for use when only small specimens are available for testing (see Tables 1 and 2).

Both Model A and Model C Mullen testers have an aperture of approximately 31 mm diameter and require that specimens be at least 125 mm in diameter for testing (ASTM, 1980a; CGSB, 1977b). Test methods requiring use of the ball burst apparatus for the Scott Tester require that specimens be of sufficient size to extend beyond the outside edge of the ring clamp mechanism (ASTM, 1980a; CGSB, 1977c). The clamping mechanism of the ball bursting apparatus for the Instron Tensile Tester has an internal diameter of 44.45 .003 mm. Specimens of several centimeters larger diameter are required for testing purposes (United States Federal Test Method Standard 191, Number 5120, 1968). Specimens of this size are not available from some knitted products, for example, vascular protheses and knitted trims.

Table 1

Specimen Size Required for Selected Diaphragm-Type Bursting Strength Methods for Knitted Fabrics

| Test Method | Aperture Diameter (mm) | Recommended Specimen Size (mm) |
|---|---|---|
| ASTM D3786-79 | 31 ± 0.75 | 125 x 125 mm square or 125 mm diameter if circular |
| CAN2-4.2-M77 Method 11.1 | 30.48 ± 0.02 | Smallest dimension of specimen must be at least 15 mm greater than the outside diameter of the ring clamp mechanism of the testing machine |
| BS 4768:1972 | 30.5 ± 0.05<br>or 113 mm | none recommended |
| ISO 2960 | 30.5 ± 0.05<br>or 113 mm | none recommended |

Table 2

Specimen Size Required for Selected Ball-Bursting Type Bursting Strength Methods for Knitted Fabrics

| Test Method | Aperture Diameter (mm) | Recommended Specimen Size (mm) |
|---|---|---|
| ASTM D3787-79 | 44.450 ± 0.025 | Of sufficient size to extend beyond the outside edge of the ring clamp mechanism of the testing machine |
| CAN2-4.2-M77 Method 11.2 | 44.45 ± 0.02 | Smallest specimen dimension must be at least 15 mm greater than the outside diameter of the ring clamp mechanism of the testing machine |
| United States Federal Test Method Standard 191, Number 5120, 1968 | 44.5 | none recommended |

## 1.1 STATEMENT OF THE PROBLEM

The problem of not being able to test smaller specimens using the regular diaphragm-type or ball bursting-type of tester has been addressed by Guidoin et al. (1978) and Hoffman and Turner (1975). Guidoin et al. have designed a new specimen holder for use with the Mullen tester, the new unit being called a mini-Mullen. Hoffman and Turner have designed a mini-probe apparatus for use on an Instron in place of a regular ball bursting apparatus. The mini-Mullen has a test aperture diameter of 11.30 mm. The Hoffman/Turner mini-probe tester has a test aperture diameter of 11.20 mm. Both are in use for the strength testing of knitted vascular prostheses. Both are also being considered for use in an international standard for synthetic tubular vascular prosthesis (ISO,1980).

To date, little work has been published on the two testers. Several different test conditions are possible with each tester. Little work has been done to establish differences in results obtained using these different test conditions. Also, it is not known if results obtained from the two testers are equivalent, if results obtained from the two testers are reproducible, or if one tester gives more precise results than the other where these terms are used according to the definitions noted in the following section.

## 1.2 DEFINITION OF TERMS

1. equivalent - results which are equal in magnitude are considered to be equivalent. For the purpose of this project, results will be considered equal in magnitude if they are not significantly different at the .01 level.
2. reproducibility - if results obtained from a test instrument are reproducible, measuring the same set of objects again and again with the same or a comparable measuring instrument will yield the same or similar results. Different operators should obtain comparable results (Kerlinger, 1965). For the purpose of this project, results will be considered to be reproducible if results obtained by two different operators are not significantly different at the .01 level.
3. precision - refers to the relative lack of spread of values obtained and is defined either by comparing measures of total variance (standard deviations, variances, standard errors of the mean) or by comparing measures of random error. The Canadian General Standards Board (1977) states that precision is an indication of the ability of a method to detect small differences and gives an indication of the number of replicate specimens needed to give an average value that is reproducible. No absolute acceptable level of precision has been defined. A 5 percent coefficient of variation, however, is not considered unusual for textile materials (Campbell, 1981).

## 1.3 OBJECTIVES

This study was designed:

1. to determine whether the Hoffman/Turner tester and the mini-Mullen tester give equivalent results when used according to specific test methods to test selected knitted fabrics
2. to determine if equivalent bursting strength results are obtained using the three sizes of diameter of probes for the Hoffman/Turner tester and if equivalent bursting strength results are obtained using the two pumping rates for the mini-Mullen tester when used according to specific test methods to test selected knitted fabrics
3. to determine whether the mini-Mullen gives more precise results than the mini-probe tester or vice versa when both are used according to specific test methods to test the bursting strength of selected knitted fabrics
4. to develop a conversion table for approximate conversion of results from one method to another (and from one test condition to another among the three sizes of probes for the Hoffman/Turner tester and between the two speeds of test for the mini-Mullen tester) if equivalent results are not obtained using the Hoffman/Turner and mini-Mullen testers.

The results of this study will contribute to filling a void in the current literature, will help those involved in quality control testing of knitted fabrics to compare measures obtained using the two testers, and will provide information to assist those responsible for writing national and international standards for vascular prostheses.

## Chapter II

## REVIEW OF LITERATURE

This chapter describes the principles of diaphragm and ball-bursting testers , and the mini-Mullen and Hoffman/Turner testers. Previous work done to compare diaphragm and ball (probe) testers is then examined. Machine factors which could affect bursting strength results are also reviewed .

### 2.1 PRINCIPLES OF DIAPHRAGM AND BALL (PROBE) BURSTING TESTERS

#### 2.1.1 Diaphragm Testers

Diaphragm testers consist of a chamber for non-compressible liquid or gas, with a circular aperture of given diameter on top. The circular aperture is covered with a rubber diaphragm. A fabric specimen is clamped over the diaphragm with a ring clamp having the same size aperture as the test chamber so that the two apertures are concentric. Pressure in the test chamber is increased at a constant rate to cause distension of the rubber diaphragm and bursting of the fabric specimen. The bursting pressure of the fabric is recorded on a dual pointer Bourdon pressure gauge by a needle indicating maximum deflection (see Fig. 1). The pressure required to raise the rubber diaphragm to the height at which the fabric bursts is then measured and subtracted from this total pressure to give the bursting strength of the specimen.

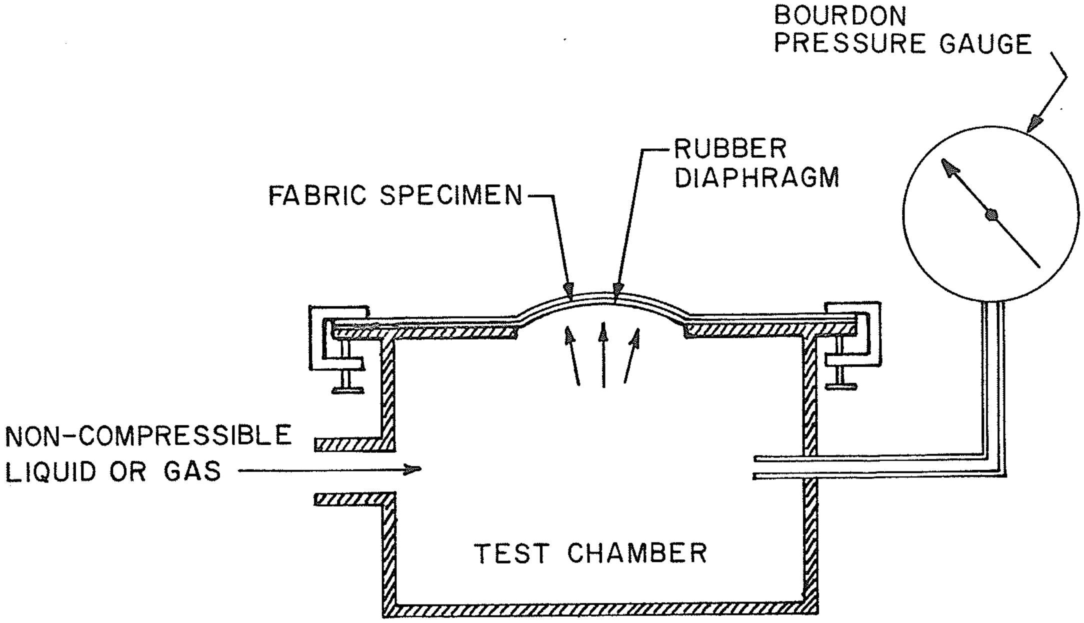


Fig. 1. Principle of Diaphragm Type Testers (adapted from Booth, 1961)

The pressure required to raise the diaphragm alone may be determined in one of two ways. In the first instance, a deflectometer may be used to record the distension of the fabric specimen at any given applied pressure (CGSB, 1977b; ISO, 1974b; BSI, 1972). The height of distension at the point of fabric burst can thus be recorded. After a specimen is burst, it is removed from the fabric clamp and burst pressure is allowed to return to zero. Then the diaphragm is distended to the height at burst again in order to determine that portion of the total bursting pressure which was necessary for distension of the rubber diaphragm alone. This pressure is then subtracted from the total pressure to give the bursting strength of the specimen. The alternative method involves holding the bursting pressure constant immediately after the specimen has failed (ASTM, 1980a). The clamping plate over the specimen is then released and the pressure required to raise the diaphragm alone, as indicated by the position of the primary gauge pointer, is then recorded and subtracted from the total pressure to give the bursting strength of the specimen.

### 2.1.2 Ball (Probe) Bursting Testers

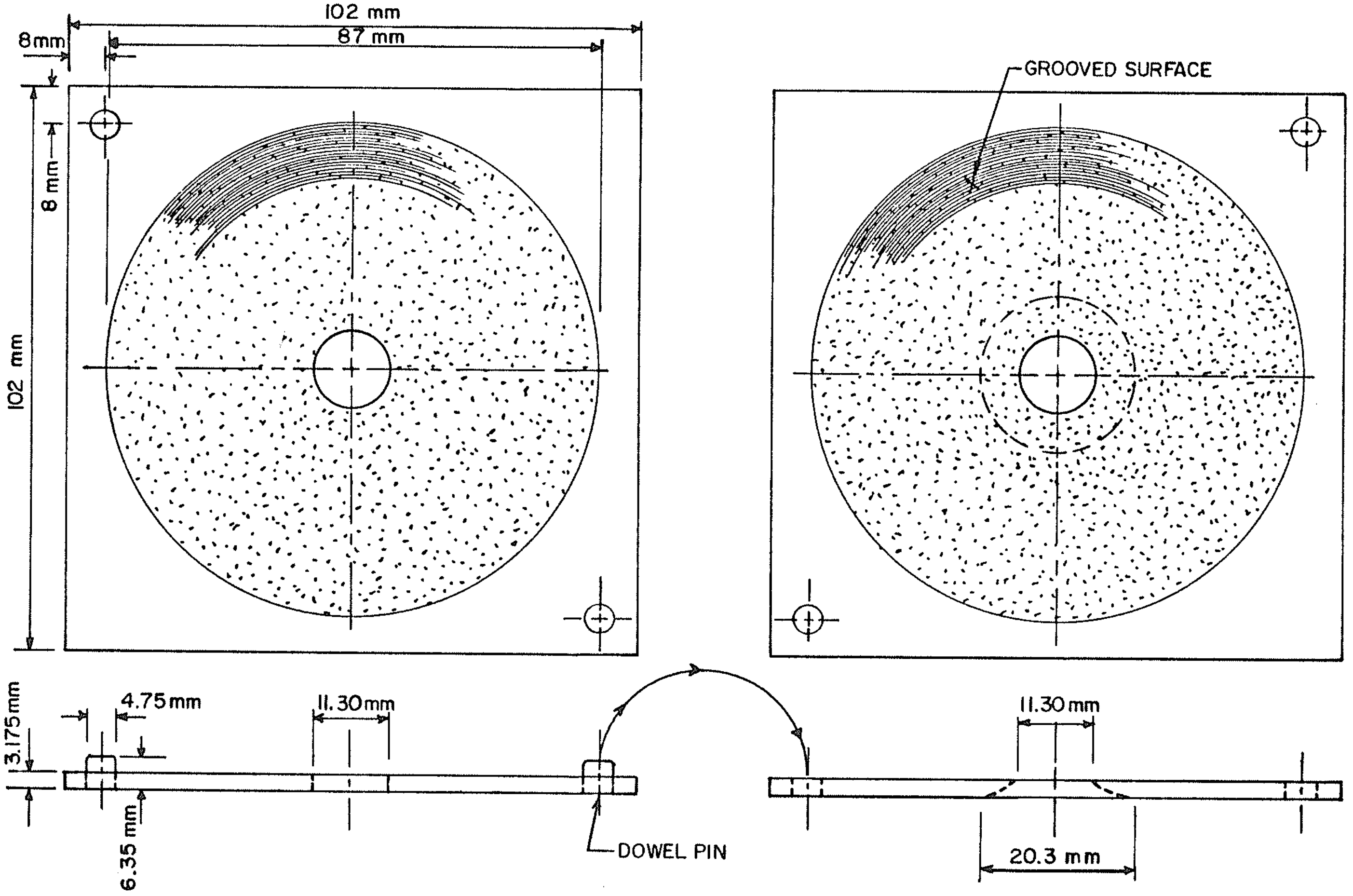
Ball bursting testers consist of an attachment by which a fabric specimen is held in an annular clamp having a test aperture of known internal diameter. The clamping apparatus is mounted on a constant-rate-of-traverse tensile tester. A metal ball of specified diameter is forced through the fabric at a given rate. Probe testers work on the same principle. In the probe test a probe of given diameter with a hemispherical end is forced through the fabric, rather than a metal ball. The maximum force required to push the probe or ball through the fabric is recorded as the bursting strength of that specimen.

## 2.2 A DESCRIPTION OF THE MINI-MULLEN AND HOFFMAN-TURNER PROBE TESTERS

### 2.2.1 The Mini-Mullen

The mini-Mullen tester consists of a modified specimen holder (Fig. 2) and special diaphragms to be used with a Model A Mullen tester. The special specimen holder has an aperture of 11.30 mm diameter rather than the regular 31 mm diameter. The specimen holder consists of a top and a bottom plate. The inner surfaces of the plates are grooved which prevents fabric slippage during testing and limits the area of fabric under test. Locating pins ensure that the apertures in the plates are exactly aligned when the plates are together. The surfaces of the clamps and any edges which might cause a cutting action are rounded to prevent specimen damage. The aperture edge of the lower clamping plate is bevelled to ensure that excessive strain is not put on the diaphragm during testing.

Fabric specimens to be tested are placed face up between the upper and lower specimen plates. The modified specimen holder is then clamped in place between the regular Model A clamping plates in such a way that the holder aperture is centered over the regular aperture.



Upper Clamping Surface

Lower Clamping Surface

Fig. 2. Modified Specimen Holder for the Mullen Tester

Regular textile diaphragms supplied for use with the Model A Mullen tester[1] lack the flexibility for use with the reduced size of aperture of the modified specimen holder of the mini-Mullen; therefore, different diaphragms are required. Diaphragms cut from latex sheeting (.012 inch thick extra heavy gauge white rubber dam material) available from The Hygenic Corporation (1245 Home Ave., Akron, Ohio 44310) were used in this project. If four thicknesses of the latex sheeting membrane are used together with a thin layer of glycerine (four drops spread evenly between each layer) the resulting composite membrane withstands up to twenty-three consecutive bursts (550 - 570 psi range) before failing. Fewer thicknesses of membrane and use of more or less glycerine between each of the four layers of membrane results in frequent membrane failure. Use of fewer membranes results in membrane failure after less than five specimen bursts in the 550 - 570 psi range. Use of more glycerine between membrane layers results in an unusual phenomenon in which the top membranes fail after being forced through the fabric in a pin-hole failure pattern. In a regular failure pattern, the membrane is forced through the fabric in one spot only with consequent yarn and fibre rupture. In a pin-hole pattern, the membrane is forced through one or more interstitial space between yarns in the fabric. If the test is allowed to proceed, the membrane bursts rather than the fabric. It is suggested that this behavior might result from stress concentrations set up in the upper membranes due to glycerine being forced towards the middle of the membranes as the test proceeds. Too little or no glycerine between the

---

[1] Diaphragm model A-12 305T available from Noram Quality Control and Research Ltd., 103 Gun, Pointe Claire, Que., or B.F.Perkins, A Division of Roehlen Industries, 939 Chicopee St., Box 366, Chicopee, Mass. 01021

membranes results in air pockets and uneven stress concentrations being set up across membranes as they are not free to slide over one another during testing. The stress concentrations lead to premature membrane failure.

### 2.2.2 The Hoffman/Turner Mini-Probe Tester

The Hoffman-Turner mini-probe tester (see Fig. 3) consists of two major parts A) a specimen holder and B) a 10.2 x 10.2 x 10.2 cm compression cage (available from W.C.Dillon Co., 14620 Keswick St., Van Nuys, Ca. 91407).

The test specimen is placed in the specimen holder. The specimen holder is mounted in the compression cage and connected to the load cell of the tensile machine. The probe is attached to the compression cage and connected to the movable cross-head. When the cross-head is lowered, the probe is pulled downward against the test specimen. A recording device linked to a strain gauge indicates the force required to drive the probe downward until the specimen ruptures.

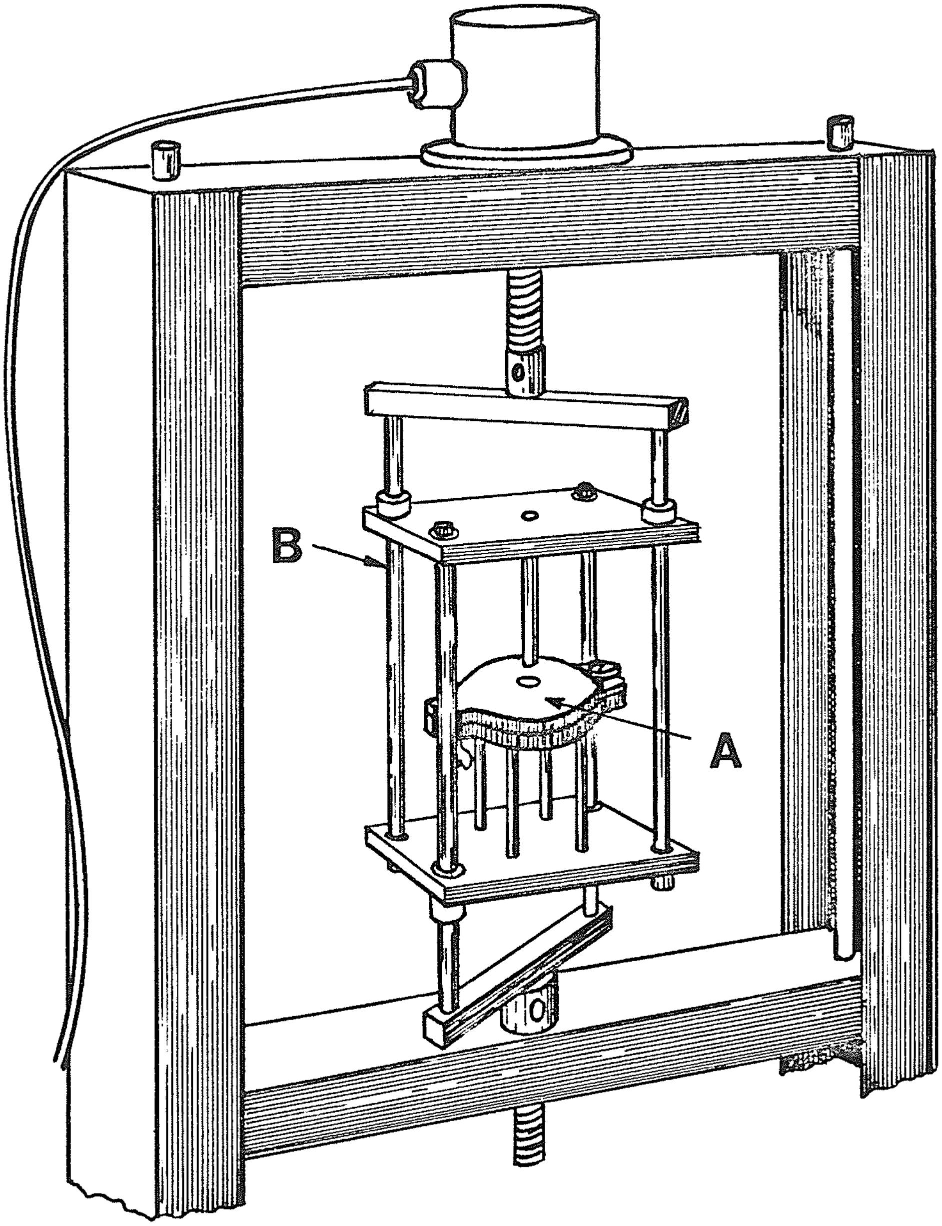


Fig. 3. The Hoffman/Turner Mini-Probe Tester Mounted on a Tensile Tester

The specimen holder (see Fig. 4) consists of an upper and a lower clamping plate. A recessed O-ring on the lower plate clamps test specimens securely against the upper plate and limits the area of specimen under test. An adjustable locating screw on the lower plate facilitates alignment of the apertures in the upper and lower plates and may be adjusted to accomodate different thicknesses of specimens. Probes of 0.64, 0.79 and 0.95 cm diameter are available for use with the tester.

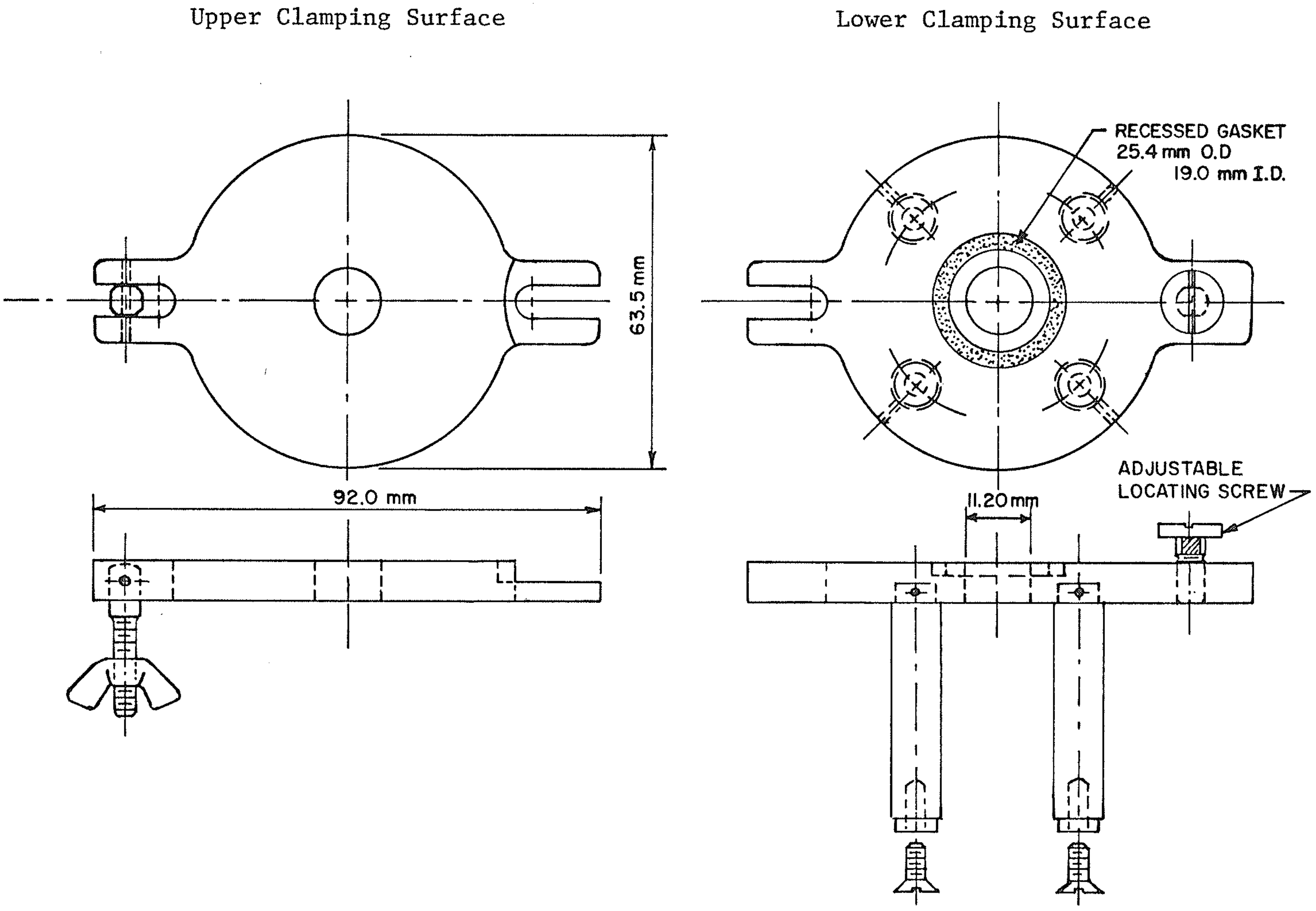


Fig. 4. Specimen Holder for Hoffman/Turner Mini-Probe Tester

## 2.3 PREVIOUS WORK DONE TO COMPARE DIAPHRAGM AND BALL-BURSTING TESTERS

### 2.3.1 Comparability Studies

The literature contains no studies designed to determine whether equivalent results are obtained using the mini-Mullen and the Hoffman/Turner testers. Previous work to compare results obtained using a conventional diaphragm versus a ball bursting tester has been limited. Norwick (1953, 1975) makes reference to (1) an interlaboratory test carried out by ASTM in which it was determined that the standard bursting test by ball and the standard diaphragm method gave different results (1975) and (2) an interlaboratory test carried out by the U.S. National Bureau of Standards in which it was determined that the two instruments gave significantly different results. He further points out, however, that the validity of the latter test is questionable as results indicated that the machines used for testing were uncalibrated (1962) and that it is unlikely that full results of the ASTM interlaboratory testing have been published (1980). Further attempts to locate the results of the ASTM study have been unsuccessful (personal communications with Dr. B. Slaten, and Mr. Al Delman, present and past chairmen of ASTM subcommittee D13-59 on bursting strength, August 6, 1980). The most recent ASTM test methods relating to bursting strength (ASTM Designations D3786 and ASTM D3787) do state, however, that the value of the bursting strength of knitted goods can only be defined in terms of a specific test method (ASTM, 1979).

### 2.3.2 Reproducibility and Precision Studies

No studies have been found in the literature on the reproducibility or precision of results obtained using the mini-Mullen and the mini-probe tester. ASTM Designation D3787 (1979) states, however, that the precision of Method D3787 for bursting strength of knitted goods using a ball bursting attachment for the constant-rate-of-traverse (CRT) tensile testing machine is being determined. As well, a precision statement for the repeated testing of fabrics of spun yarn in circular knits and for filament yarns in tricot knits is included in ASTM Designation D 3786 (1979): Standard Test Method for Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabrics - Diaphragm Bursting Strength Tester Method.

### 2.3.3 Studies Establishing The Effect of Using Different Sized Probes On Bursting Strength Results

Hoffman and Turner (1979), using probes of 0.64, 0.79, and 0.95 cm. diameter, in an aperture of constant diameter, showed that as the diameter of the probe increases, the observed bursting strength values increase. The same effect has been noted with results obtained using the conventional ball-bursting tester with an aperture of constant diameter and balls with the diameters increasing from 1.91 to 3.81 in 0.64 cm increments (Table 1, Whitcomb 1928, pp. 44).

## 2.4 FACTORS AFFECTING BURSTING STRENGTH MEASUREMENTS

### 2.4.1 Factors Affecting the Results of Mullen Bursting Strength Measurements

Machine factors which could affect the results of bursting strength measurements obtained using Mullen testers are well documented (Athey, 1980; Norwick, 1975; BSI, 1974; Garner, 1967; Booth, 1961; Jacobsen, 1961; Lomax, 1961; Skinkle, 1949; Tuck, Faichney and Mason, 1953; Tuck and Mason, 1949; Davis and Howards, 1936; Foster, 1925). These include diameter of the test aperture, rate of loading, properties of the rubber diaphragm, air in the tester, gauge inaccuracies, clamping pressure and conditions and the weight of the deflectometer disc, if used. Each of these factors will be discussed in turn.

#### 2.4.1.1 Test Aperture Diameter

That the use of a Mullen tester with a larger diameter gives lower mean bursting strength values has long been recognized (Norwick, 1975; ISO, 1974; BSI, 1974; Garner, 1967; Lomax, 1961; Skinkle, 1949; Davis and Edwards, 1936; Foster, 1925). Garner (1967) states that using the Mullen with a 3.05 mm aperture rather than the larger 31 mm aperture can give bursting strength results 10 - 25 percent higher, and that using a 101.6 mm aperture will give figures much less than one-half of the 31 mm aperture Mullen results. The lower mean of bursting strength may be expected since the area of the test sample increases as the square of its diameter so that the chance of including a weak part of the fabric in the test is greater (Davis and Edwards, 1936). It follows that dispersion of the readings will increase with reduction of the test diameter.

### 2.4.1.2 Rate of Loading

The rate of loading may have a considerable influence on the tensile strength shown by textile materials. Too rapid application of stress can give inflated values (Morton, 1962). However, in bursting strength testing, the rate of loading does not appear to affect the result to an appreciable degree (Lomax, 1961). All of the standard test methods examined require that the rate of loading be as specified, or that the the rate of loading used be specified.

### 2.4.1.3 Properties of the Rubber Diaphragm

The rubber diaphragm is interposed between the fabric and the liquid under pressure. Therefore, part of the total pressure required to burst a specimen is that required to raise the diaphragm to its height at fabric burst. As elastic properties of the diaphragm are known to vary with age, usage (Whitcomb, 1928) and height of distention (Lomax, 1961), it is necessary, for each specimen tested, to measure the pressure required to raise the diaphragm alone to the height at bursting pressure.

### 2.4.1.4 Air in the Tester

Air in the test chamber of the Mullen may cause artificially low test results. The problem arises because air can be compressed with increasing pressure, unlike the noncompressible liquid (glycerine or ethylene glycol) in the test chamber. As pressure in the test chamber is increased, the effective pumping rate of the liquid is lowered, resulting in decreased bursting strength values (Tuck and Mason, 1949). A method of removing trapped air is described in the B.F. Perkins manual accompanying the Mullen and by Tuck and Mason (1949).

### 2.4.1.5 Gauge Inaccuracies

Tuck, Faichney and Mason (1953) and Tuck and Mason (1949) have described factors affecting the accuracy of Mullen gauges including (1) inertia of the gauge mechanism, (2) friction in the gauge mechanism, (3) the rate of increase of pressure and (4) gauge expansibility. Some of these errors, for example constant gauge deviations, gauge deviations proportional to the applied pressure and deviations due to incorrect contours or worn pinion or sector teeth, sticking bearings and dirty mechanisms, can be detected by calibration with a deadweight tester. Other errors are only detectable using dynamic calibration techniques, for example, (1) frictional error due to the needle indicating the deflection exerting a pressure on the static pressure needle mechanism and (2) an overshoot error caused by the needle indicating the maximum deflection tending to continue in motion after the fabric bursts. Tuck and Mason (1949) state that the dynamic errors in well adjusted gauges are in the order of 2 percent and are generally high because of needle overthrow and that those of badly adjusted gauges can be considerably higher.

Gauge expansibility, defined as the amount of liquid entering the gauge Bourdon tube per unit increase in pressure when no air is present, is determined through use of a dilatometer.

### 2.4.1.6 Weight of the Deflectometer Disc

If the deflectometer disc is used and is excessively heavy, error in distension measurements can result due to decreased diaphragm extension. Few researchers have examined the effect of the weight of the disc, however Tuck and Mason (1936) concluded that it had a negligible effect on results for paper testing. A deflectometer was not used in this project.

### 2.4.1.7 Clamping Pressure and Methods

Adequate clamping pressure is necessary to prevent slippage of the fabric specimen. Too high a clamping pressure can result in damage to the fabric during test and an excessive number of discarded specimens due to jaw breaks. Clamping surfaces must be uniform to prevent specimen slippage. The apertures of clamping surfaces must also be concentric to prevent jaw breaks.

### 2.4.1.8 Gauge Accuracy

Mullen Helicoid gauges are accurate to .005 percent of the scale range.

## 2.4.2 Factors Affecting Results of Bursting Strength Measurements Obtained Using the Mini-Probe Tester

### 2.4.2.1 Factors Common To The Mini-Mullen Tester

Machine factors which could affect the results of bursting strength measurements obtained using the mini-probe tester that are common to the mini-Mullen tester include diameter of the test aperture, the rate of loading and the clamping pressure. These possible effects are described above. Other factors which could affect test results include diameter of the probes, alignment of the probes in the aperture, surface smoothness of the probes and accuracy of the Instron. Each of these factors will be discussed in turn.

### 2.4.2.2 Diameter of the Test Probe

Hoffman and Turner (1975), using probes of 0.64, 0.79, and 0.95 cm diameter in an aperture of constant diameter, showed that as the diameter of the probe increases, the observed bursting strength values increase. The same effect has been noted with results obtained using the conventional ball-bursting tester with an aperture of constant diameter and ball diameter increasing from 1.91 to 3.81 in 0.64 cm increments (Table 1, Whitcomb 1928, pp. 44).

### 2.4.2.3 Alignment of the Probes In The Aperture

Results of preliminary trials in the University of Manitoba Textile Testing Laboratory indicate that misalignment of a probe in the aperture can lead to less precise results and jaw breaks.

### 2.4.2.4 Surface Smoothness of the Probes

Rough spots on the probes could lead to non-uniform stressing and erroneous bursting strength results with the fabric bursts occurring as a result of fibres being cut.

### 2.4.2.5 Accuracy of the Instron

The load weighing accuracy of the Instron Model TM Tensile Tester is 0.5 percent of the indicated load or 0.25 percent of the recorder scale in use, whichever is greater, for all ranges. The crosshead accuracy is better than 1 percent for all crosshead speeds and loads. The pen response of the graphic strip chart recorder is 1.0 second full scale or 3.0 seconds for 0.5 percent dynamic accuracy.

# Chapter III

# METHODOLOGY

The test equipment used, methods of testing, selection of samples and specimens, and methods of analysis are described in this chapter.

## 3.1 TEST EQUIPMENT

### 3.1.1 The Mini-Probe Tester

A mini-probe tester similar to that designed by Hoffman and Turner was constructed for this project, using a W.C. Dillon Co. compression cage (14620 Keswick St., Van Nuys, Ca. 91407). Two minor design modifications were introduced to provide an easier way to center the probes in the test aperture (see Fig. 5). First, Allen screws were inserted in the lower clamping plate of the specimen holder to allow minor adjustments of the position of the bottom clamping plate. Secondly, a centering device was constructed for each probe to aid in checking its alignment in the test holder aperture, as well as the alignment of the two plates.[2]

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[2] Construction of the specimen holder and probes and assembly of the holder and cage was by Central Instrument Services at the University of Manitoba, Winnipeg, Manitoba.

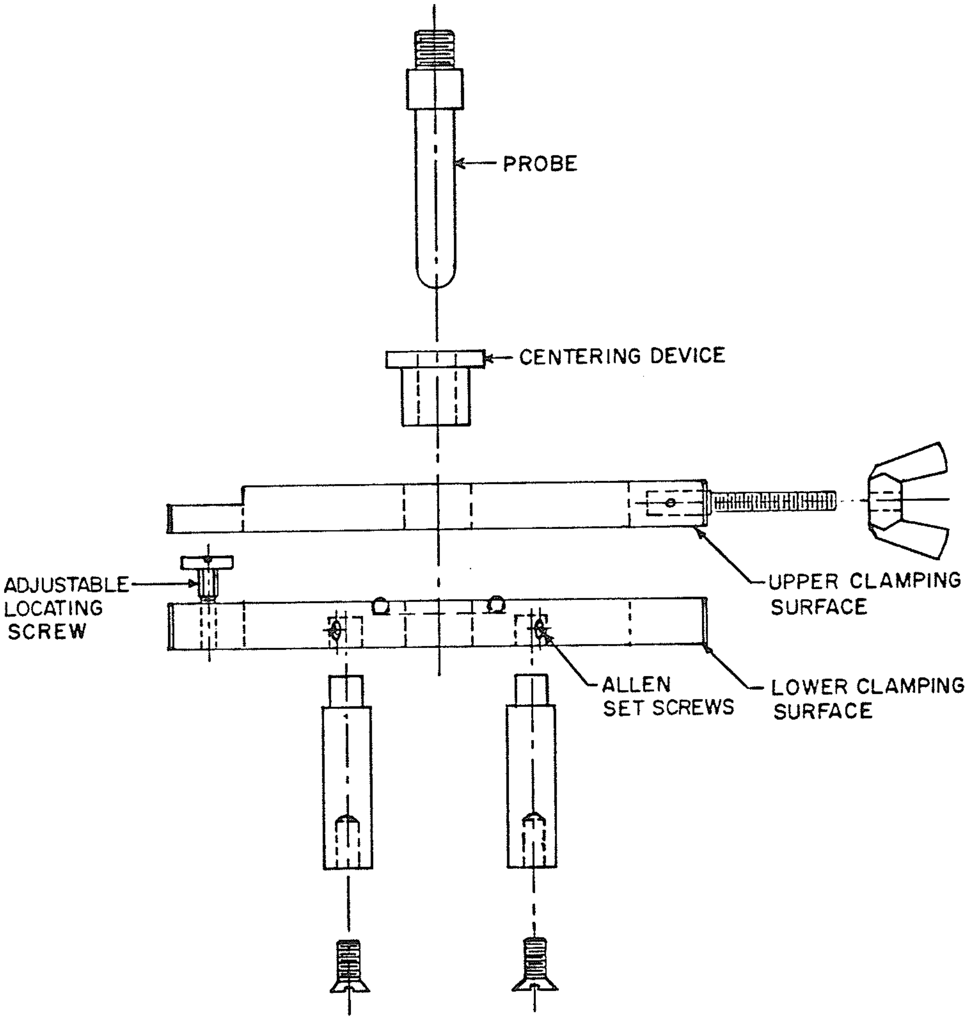

Fig. 5. Fabric Clamp for Mini-Probe Tester with Allen Screws for Adjustment of Position of Lower Clamping Plate and Centering Device for Probes

Smoothness of the finished probes was assessed according to General Electric Roughness Standards - Catalogue No. 342X61 (on loan courtesy of Dominion Bridge Co. Ltd., 845 Logan Ave., Winnipeg, Manitoba). All probes were given a roughness range rating of 4-16 microinches (1 micron x 39.37008) when viewed under North Sky Daylight.

### 3.1.2 The Mini-Mullen Tester

Mini-Mullen bursting strength results were obtained using a B.F. Perkins Model A Mullen tester. Two different motors were purchased for use with the tester: one with a pumping rate of 17 ml/min, the other with a pumping rate of 170 ml/min. The pumping rate of 17 ml/min corresponds to that normally achieved with a Model AD Mullen tester (a Model A tester with a deflectometer attachment); while the pumping rate of 170 ml/min corresponds with that normally achieved with newer Model A Mullen testers (older Model A Mullens have a variable speed motor so the pumping rate can be varied). The motors with pumping rates of 170 ml/min and 17 ml/min were chosen as representative of what is currently available with Model A Mullens. The mini-Mullen specimen holder used was donated by Dr. R.G. Guidoin, Université Laval, Québec City and fabricated at Centre des Recherches Industrielles de Québec, Québec City.

Diaphragm material for the mini-Mullen tester was supplied in the form of latex sheeting from The Hygenic Corporation, (1245 Home Ave., Akron, Ohio, 44310).

## 3.2 METHODS OF TESTING

### 3.2.1 Pretesting

Pretesting procedures were designed to determine whether results obtained using the two testers were reproducible and to ensure that test equipment was functioning properly.

#### 3.2.1.1 Equipment Check

Mullen gauges were calibrated statically, dynamically, and for expansibility prior to beginning testing.[3] Actual pumping rates for the Mullen motors were determined to be 16.3 ml/min and 160.7 ml/min according to ISO 2758 (ISO, 1974a) over an average of ten trials. Uniformity of clamping and concentricity of the clamp apertures of both the mini-Mullen and mini-probe testers was checked and found to be satisfactory according to the same standard.

The Instron Model TM graphic strip chart recorder pen response and crosshead accuracy were determined to be within the manufacturer's stated range (pen response of less than 1 second full scale and better than 1 percent cross-head speed accuracy). The Instron was calibrated for load weighing accuracy prior to the testing of each fabric with each probe. The given load weighing accuracy for the Instron is 0.5 percent of the indicated load or 0.25 percent of the recorder scale in use, whichever is greater.

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[3] Calibration was by the Pulp and Paper Research Institute of Canada, 570 St. John's Road, Pointe Claire 720, Quebec H9R 3J9.

### 3.2.1.2 Reproducibility Testing

Twenty specimens of standard aluminum test foil available from the Pulp and Paper Research Institute of Canada, (570 St. John's Road, Pointe Claire 720, Quebec, H9R 3J9) were tested by each of two operators using both the mini-Mullen and Hoffman/Turner mini-probe tester to determine if test methods were reproducible. These tests used the three probe sizes available for use with the Hoffman/Turner tester and one of the pumping rates available for the Mullen. Foil was used rather than fabric to reduce variability in results attributable to factors other than interoperator variance. All testing was carried out in the standard atmosphere for testile testing (20 ± 1°C, 65 ± 2% relative humidity).

### 3.2.2. Final Testing

Thirty specimens were cut for testing for each of the five bursting strength procedures from each fabric (one specimen for each size of probe of the Hoffman/Turner tester, and one for each Mullen speed). All testing was carried out in the standard atmosphere for textile testing. Specimens were conditioned in the standard atmosphere for forty-eight hours prior to testing.

### 3.2.2.1 Hoffman/Turner Mini-Probe Tester

The bursting strength (kg force) and time to burst (seconds) were recorded for each specimen according to a procedure outlined by Hoffman and Turner (1975). The rate of test was set at 12.70 cm/min for all fabrics. Specimens were placed face down for testing. Probes were cleaned by immersion in trichlorethylene after every ten specimens to remove any film of oil or foreign particles which may have accumulated during testing according to a procedure noted in U.S. Federal Test Method Standard 191, Method 5120: Strength of Cloth; Ball Bursting Method (1968).

### 3.2.2.2 The Mini-Mullen Tester

The bursting pressure (psi) and time to burst (seconds) were recorded for each specimen according to ASTM D3786-80a. Bursting pressure was recorded as the total pressure required to rupture the specimen minus the tare pressure required to raise the diaphragm alone to its height of distension at specimen burst. Specimens were placed face up for testing. Diaphragms were replaced after every five tests.

## 3.3 SELECTION OF SAMPLES AND SPECIMENS

A nonprobability sample of 58 knitted fabrics was selected from those available on the Winnipeg market using a purposive sampling technique. Weft knits of single jersey, rib and doubleknit construction and warp knits of tricot were included in the sample. Purl, raschel and pile knits were excluded as it is unlikely that they would be used in a construction that would not allow testing in a conventional manner. Fabrics containing structural discontinuities, for example lacy effects, were omitted from the selection, as such fabrics could introduce uncontrollable variation in test results.

As extensibility is known to be a major factor affecting bursting strength results (Athey, 1980; Norwick, 1962, 1975; BSI, 1974; ISO, 1974; Booth, 1961), fabrics were chosen to represent the range of extensibilities of knitted fabrics available. Extensibility may be defined as the ease of stretching (Kaswell, 1961). After purchase, the range of extensibilities of fabrics acquired was determined using the mini- probe tester. The 0.95 cm. probe was arbitrarily selected for use in this procedure. A constant-time-to-burst principle was employed. The rate of test was adjusted so that all specimens burst within 20 ± 3 seconds. Two specimens of each fabric were tested to give an average extension at burst where extension at burst represents the vertical distance the probe travels from a position just above the fabric surface at the beginning of test to the position at which the fabric burst. Values for the fifty-eight fabrics ranged from 0.41 cm to 2.07 cm. Extensibility values ranged from 0.41 cm to 2.07 cm for the tricot fabrics, from 0.45 cm to 1.07 cm for the single jersey fabrics, from 0.53 cm to 1.59 cm for the rib fabrics and 0.55 cm to 0.93 cm for the doubleknit fabrics.

Twenty of the fifty-eight fabrics were then selected for final testing. To maintain a wide range of extensibilities for warp and weft subgroups as well as for the entire population, fabrics were first grouped according to fabric type (single jersey, rib, doubleknit, or tricot) and extensibility (see Table 3, Appendix A). Five fabrics were then chosen from each group using a table of random numbers (Beyer, 1978).

In the tricot, single jersey and rib groups where there were clearly fabrics outside the "normal range" of extensibilities due to the presence of elastic or very highly crimped yarns, one of the five fabrics chosen for each group was randomly chosen from this category. The other four fabrics were chosen randomly from those remaining. In the doubleknit group, where all the fabrics appeared to fall within one distribution, all five fabrics were selected randomly.

A description of fabric characteristics of the selected fabrics is found in Table 4. Fabric thickness was determined according to Canadian National Standard CAN2-4.2-M77 Method 37-1977 (CGSB, 1977) using a Frazier Compressometer (Frazier Precision Instrument Company, 8913 Glenville Road, Silver Spring, Maryland). Measurements were obtained using the 25.4 mm and 76.2 mm diameter feet and a pressure of 0.69 kPa. Fabric count was determined according to Canadian National Standard CAN2-4.2-M77 Method 7-1977 (CGSB,1977). Fabric weight was determined according to Canadian National Standard CAN2-4.2-M77 Method 5.A-1977 (CGSB, 1977).

## Table 4

Description of Fabric Characteristics*

| Fabric Number | Type of Knit | Fibre Content | Fabric Count** | | Fabric Thickness**(cm) | | Weight (g/m$^2$) |
|---|---|---|---|---|---|---|---|
| | | | Courses/cm | Wales/cm | Mean | SD | |
| 12 | Tricot | polyester/nylon | 20.7 | 11.8 | 0.038 | .001 | 134.38 |
| 25 | | nylon/polyurethane | 27.1 | 27.4 | 0.071 | .001 | 179.93 |
| 29 | | nylon/triacetate | 12.5 | 12.4 | 0.052 | .002 | 151.99 |
| 33 | | nylon/triacetate | 16.3 | 16.4 | 0.026 | .001 | 83.78 |
| 37 | | polyester/triacetate | 15.4 | 15.5 | 0.038 | .001 | 133.38 |
| 03 | Single Jersey | 60/40 cotton/polyester | 12.8 | 14.4 | 0.080 | .001 | 169.94 |
| 08 | | cotton/polyester | 10.6 | 9.3 | 0.189 | .004 | 226.90 |
| 16 | | 80/20 cotton/polyester | 21.7 | 19.6 | 0.210 | .001 | 219.46 |
| 43 | | 80/20 acrylic/polyester | 60.2 | 57.8 | 0.198 | .003 | 206.11 |
| 58 | | 80/20 cotton/polyester | 14.0 | 9.7 | 0.208 | .006 | 242.06 |
| 04 | Rib | 100% nylon | 7.0 | 12.0 | 0.160 | .005 | 252.37 |
| 06 | | 100% polyester | 14.2 | 34.1 | 0.292 | .004 | 402.86 |
| 14 | | cotton/polyester | 12.4 | 24.2 | 0.086 | .001 | 191.98 |
| 49 | | 100% nylon | 19.2 | 16.4 | 0.097 | .001 | 187.75 |
| 50 | | 50/50 cotton/polyester | 10.8 | 15.0 | 0.107 | .002 | 209.53 |
| 15 | Doubleknit | 100% cotton | 12.0 | 15.0 | 0.085 | .002 | 168.12 |
| 20 | | 100% polyester | 20.8 | 12.9 | 0.055 | .002 | 152.58 |
| 24 | | polyester/wool/acrylic | 6.0 | 5.6 | 0.171 | .002 | 241.60 |
| 32 | | 100% nylon | 12.7 | 14.0 | 0.057 | .001 | 95.68 |
| 55 | | 100% polyester | 10.2 | 5.3 | 0.113 | .005 | 139.64 |

*determined according to standard test methods.
**Figures noted are the average of 5 observations.

### 3.3.1 Specimen Selection

Fabrics were conditioned for 48 hours in a standard atmosphere (21 ± 1°C, 65 ± 2% relative humidity) prior to specimen selection. Specimens were selected according to procedures outlined in ASTM Designations D3786-80a and D3787-80a. Thirty specimens, each 40 x 60 mm, were selected and cut from each fabric for each test procedure: one specimen for each of the three sizes of probes available for use with the mini-probe tester and one for each of the two rates of test used with the Mullen.

## 3.4 METHODS OF ANALYSIS

### 3.4.1 Conversion of Results to a Common Unit

Bursting strength results from the mini-Mullen tester and Hoffman/Turner mini-probe tester were first converted to common units, kilopascals (kPa), by multiplication by the appropriate conversion factor (see Table 5).

Table 5

Conversion of Mini-Mullen and Hoffman/Turner Mini-Probe Results to Kilopascals (kPa)

| Tester | Unit of Measure | Conversion Factor |
|---|---|---|
| Mini-Mullen | psi | x 6.89476 |
| Hoffman/Turner mini-probe tester | kg force | x 25.798148† |

†given that 1 $kgf/m^2$=9.80665 Pa and that diameter of test area = 2.20 cm

## 3.5 ASSUMPTIONS

Assumptions have been made that:

1. the mini-Mullen and the Hoffman/Turner mini-probe tester are valid instruments for the measurements of bursting strengths of knitted fabrics and
2. the knitted fabrics selected for testing are representative of the population from which they were chosen.

### 3.5.1 Analysis of Results For Each Objective

Results for the reproducibility testing on foil between two operators were analyzed using an analysis of variance technique.

Equivalency of bursting strength results between the Hoffman/Turner and mini-Mullen testers, and between different test conditions for each tester was established through comparison of bursting strength means and analysis of variance techniques.

The relative precision of results obtained using the two testers was determined by comparison of percent coefficients of variation calculated first on the basis of total variance for each fabric and for each type of fabric for each test condition, and then on the basis of error variance (from analysis of variance data) for each fabric type for the mini-Mullen and Hoffman/Turner testers.

Pearson product-moment coefficients of correlation were determined for all possible combinations of different test methods, both between results from the Hoffman/Turner and mini-Mullen testers and within test conditions for each tester, for the twenty fabrics as a whole and for the four groups of fabrics. Conversion factors for estimating the results of one test condition given the results of another were developed where "strong" correlations were identified.

A $p < .01$ level of significance was chosen for use in all analyses.

## Chapter IV

## RESULTS AND DISCUSSION

Results of the reproducibility testing with standard foil and of the final testing with the twenty fabrics are presented and discussed in relation to project objectives. Possible reasons for the observed results are then examined and lastly, some practical considerations in the use of the two testers are discussed.

### 4.1 REPRODUCIBILITY TESTING

Table 6 summarizes standard foil bursting strength results obtained by two operators using the Hoffman/Turner mini-probe tester and the Mullen tester operated at 170 ml/min. An analysis of variance indicated that results did not differ significantly for the two operators (Table 7, F=.06).

Table 6

Mean Hoffman/Turner and Mini-Mullen Bursting Strength Results (kPa) for Standard Aluminum Foil[†] Testing for Two Operators

| | Hoffman/Turner 0.64 cm probe | | Hoffman/Turner 0.79 cm probe | | Hoffman/Turner 0.95 cm probe | | Mullen (170 ml/min) | |
|---|---|---|---|---|---|---|---|---|
| Operator | Mean | SE[††] | Mean | SE | Mean | SE | Mean | SE |
| 1 | 172.1 | 1.1 | 219.7 | 1.0 | 255.9 | 1.1 | 2156.5 | 8.0 |
| 2 | 179.6 | 1.6 | 225.6 | 1.4 | 266.3 | 1.7 | 2128.8 | 10.7 |

[†] foil burst value = 143.0 ± 4 psi; date = May 30, 1979

[††] SE = standard error of the mean = $\frac{\text{standard deviation}}{\sqrt{n}}$

Table 7

Analysis of Variance for Hoffman/Turner and Mullen Bursting Strength Results as a Function of Operators and Methods of Test

| Source | degrees of freedom | sum of squares | mean of squares | F-ratio |
|---|---|---|---|---|
| Operators | 1 | 300.5 | 300.5 | 0.6 |
| Methods | 3 | 110654665.8 | 36884888.6 | 76547.6** |
| Operator x Methods | 3 | 13717.2 | 4572.4 | 9.4** |
| Error | 152 | 73242.0 | 481.8 | |
| Total | 159 | 110741925.6 | | |

**p<.01

## 4.2 FINAL TESTING

Table 8 summarizes fabric bursting strength results obtained using the Hoffman/Turner mini-probe tester and the mini-Mullen tester. Mullen results for fabric 04 are excluded as testing attempts resulted in failure of the membrane rather than the fabric. It is believed that the low fabric count and high extensibility of this fabric (Tables 3 and 4) allowed the membrane to be forced through interstitial space between the yarns causing highly localized pressure concentrations under the membrane and a pin-hole failure mechanism. This problem was not observed with fabrics with higher counts, or with less extensible fabrics of lower count.

### 4.2.1 Equivalency of Hoffman/Turner and Mullen Results

The primary objective of this project was to determine whether the Hoffman/Turner and Mullen testers would give equivalent mean bursting strength results when used according to specific test methods to test selected knitted fabrics. Results in Table 8 clearly show that the Mullen tester, at pumping rates of both 17 ml/min and 170 ml/min consistently gave results of greater magnitude than the Hoffman/Turner tester, irrespective of whether results were obtained using the 0.64, 0.79, or the 0.95 cm probe. Similar findings were obtained during the foil testing with the 170 ml/min Mullen (Table 6).

## Table 8

Mean Hoffman/Turner and Mini-Mullen Bursting Strength Results (kPa)

| | Hoffman/Turner 0.64 cm probe | | Hoffman/Turner 0.79 cm probe | | Hoffman/Turner 0.95 cm probe | | Mini-Mullen (170 ml/min) | | Mini-Mullen (17 ml/min) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fabric† | Mean | SE†† | Mean | SE | Mean | SE | Mean | SE | Mean | SE |
| A 12 | 620.96 | 2.96 | 803.53 | 5.31 | 940.61 | 9.78 | 4053.0 | 9.5 | 4135.4 | 9.6 |
| 25 | 244.40 | 2.06 | 300.73 | 2.37 | 363.06 | 2.43 | 869.9 | 6.7 | 950.7 | 4.6 |
| 29 | 239.75 | 1.41 | 304.07 | 2.12 | 366.00 | 2.88 | 1630.6 | 16.1 | 1646.0 | 9.3 |
| 33 | 166.22 | 1.88 | 213.51 | 2.28 | 252.39 | 3.31 | 1112.3 | 8.7 | 1196.7 | 9.1 |
| 37 | 301.84 | 3.26 | 370.47 | 4.30 | 435.12 | 4.89 | 1647.4 | 11.5 | 1680.1 | 5.9 |
| B 04 | 663.70 | 17.67 | 898.90 | 15.33 | 1097.55 | 11.16 | -- | -- | -- | -- |
| 06 | 538.15 | 7.48 | 658.55 | 5.61 | 791.75 | 7.39 | 2001.6 | 17.6 | 2155.6 | 46.2 |
| 14 | 286.19 | 5.01 | 375.19 | 6.27 | 457.04 | 8.25 | 2008.4 | 41.4 | 2104.9 | 38.2 |
| 49 | 421.11 | 3.15 | 525.17 | 4.05 | 638.42 | 4.99 | 1660.9 | 5.8 | 1608.0 | 6.7 |
| 50 | 414.14 | 9.23 | 533.07 | 9.04 | 614.43 | 6.65 | 2620.7 | 30.9 | 2602.2 | 37.7 |
| C 15 | 256.51 | 4.11 | 317.93 | 4.87 | 399.19 | 6.06 | 1786.9 | 23.4 | 1784.1 | 20.6 |
| 20 | 720.45 | 3.73 | 873.96 | 10.76 | 1122.91 | 3.90 | 3921.9 | 12.9 | 3928.3 | 17.8 |
| 24 | 418.18 | 7.46 | 567.04 | 13.07 | 682.02 | 15.24 | 2674.5 | 46.7 | 2560.3 | 32.6 |
| 32 | 433.07 | 7.82 | 587.00 | 7.19 | 724.67 | 6.94 | 2306.3 | 10.7 | 2325.5 | 12.7 |
| 55 | 404.52 | 6.34 | 565.15 | 5.32 | 674.37 | 5.13 | 2007.5 | 33.3 | 2063.0 | 31.2 |
| D 03 | 306.05 | 1.95 | 399.27 | 2.92 | 458.44 | 2.71 | 1912.0 | 13.3 | 1998.4 | 10.6 |
| 08 | 268.82 | 4.29 | 336.07 | 5.46 | 407.17 | 7.37 | 1715.4 | 18.3 | 1925.4 | 24.6 |
| 16 | 189.27 | 2.01 | 240.35 | 1.83 | 288.43 | 1.72 | 998.2 | 5.3 | 1131.4 | 6.3 |
| 43 | 158.58 | 0.85 | 203.20 | 1.78 | 245.07 | 1.42 | 1106.1 | 5.9 | 1218.5 | 4.6 |
| 58 | 257.81 | 1.38 | 336.59 | 1.67 | 396.35 | 2.74 | 1810.8 | 7.2 | 1869.4 | 6.0 |

†Fabric group A = tricot knits, group B = rib knits, group C = doubleknits, group D = single jersey knits.
††SE = standard error of the mean
--Fabric not possible to test

### 4.2.2 Equivalency of Probe Results and of Mullen Results

A second major objective was to determine whether equivalent mean bursting strength results would be obtained using the 0.64, 0.79 and 0.95 cm diameter probes with the Hoffman/Turner tester and similarly, whether equivalent mean bursting strength results would be obtained using the 17 ml/min and the 170 ml/min pumping rate with the Mullen tester. Results in Tables 8 and 9 show that mean bursting strength increased as the probe diameter increased. Similar results were obtained during the foil testing (Table 6). An analysis of variance (Table 10, F=107.81) confirmed that the main effect of probe size was significant ($p<.01$).

Table 9

Mean Hoffman/Turner and Mini-Mullen Bursting Strength Results (kPa) by Fabric Type

| Fabric Type | Hoffman/Turner 0.64 cm probe | Hoffman/Turner 0.79 cm probe | Hoffman/Turner 0.95 cm probe | Mini-Mullen (170 ml/min) | Mini-Mullen (17 ml/min) |
|---|---|---|---|---|---|
| tricot | 314.63 | 398.46 | 471.44 | 1862.6 | 1921.8 |
| rib | 464.66 | 598.18 | 719.84 | 2072.9 | 2117.7 |
| doubleknit | 446.55 | 582.22 | 720.63 | 2539.4 | 2532.2 |
| single jersey | 236.11 | 303.10 | 359.09 | 1508.5 | 1628.6 |

Table 10

Analysis of Variance for Hoffman/Turner Bursting Strength Results as a Function of Probe Size and Fabric Type

| Source | degrees of freedom | sum of squares | mean of squares | F-ratio |
|---|---|---|---|---|
| Whole unit | | | | |
| fabric type | 3 | 944,330.00 | 314,776.67 | 3.04 |
| error term | 16 | 1,654,743.41 | 103,421.46 | |
| Subunit | | | | |
| probe size | 2 | 409,309.00 | 204,654.50 | 107.81** |
| probe size x fabric type | 6 | 40,896.83 | 6,816.14 | 3.59** |
| error term | 32 | 60,745.95 | 1,898.31 | |

**p<.01

Results in Table 10 also show that interaction was found to exist between probe size and fabric type (F=3.59, p<.01), and that the main effect of fabric type was not significant (F=3.04). In other words, a similar range of fabric strengths was found within each fabric type.

Figure 6 illustrates that the mean bursting strength for fabric types increases with increasing probe size. It also shows that the rate of increase is different with different fabric types. As probe size increases, mean bursting strengths show greater increases with rib and doubleknit types than with the single jersey and tricot types.

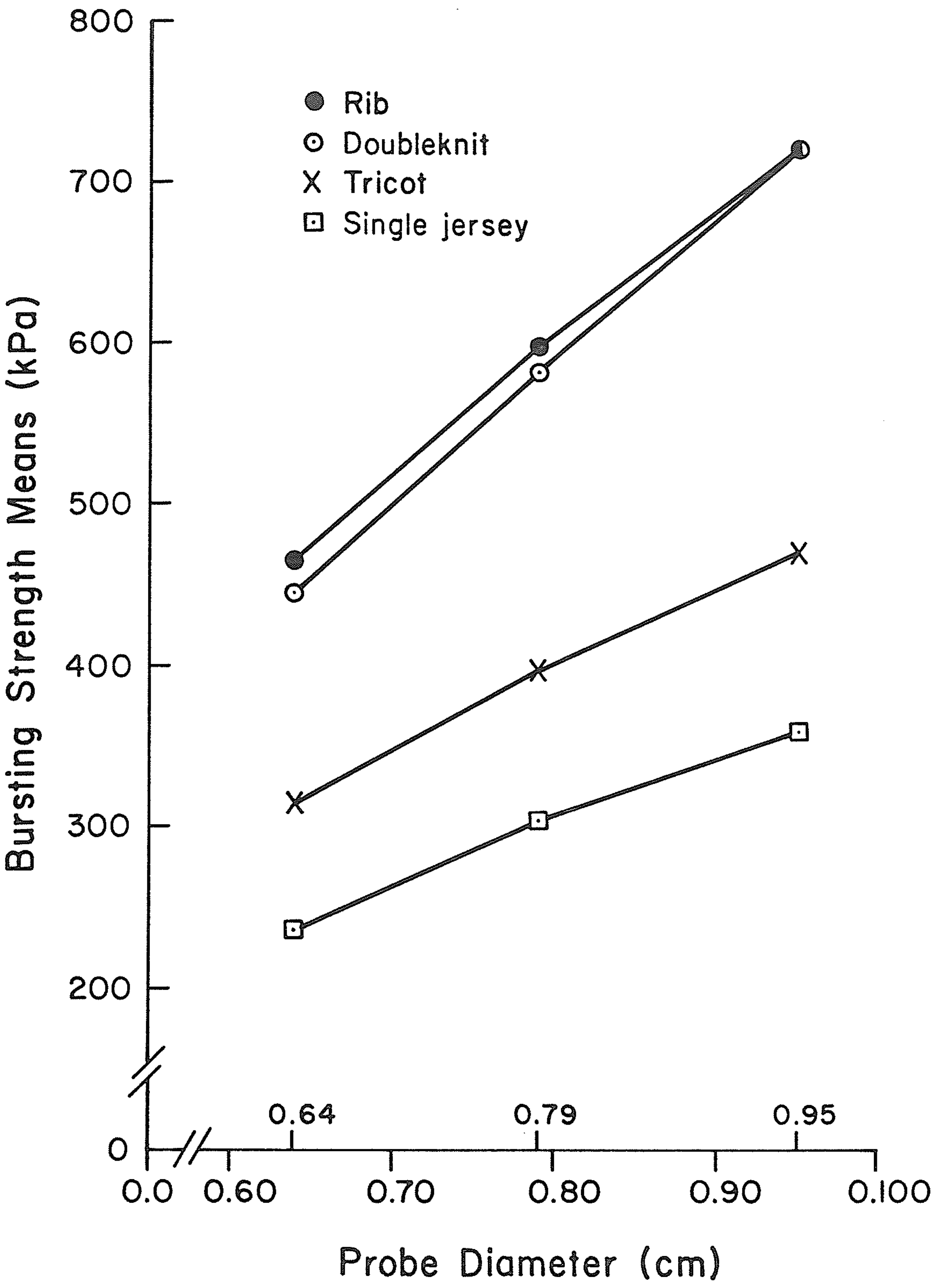

Fig. 6. Bursting Strength Means (kPa) Versus Probe Diameter for the Fabric Types

Table 11 shows results of an analysis of variance of the Mullen tester results. The F ratios show that the main effect of fabric type was not significant (F=0.24), that the main effect of rate of test was not significant (F=2.85) and that no interaction was found to exist between rate of test and fabric type (F=.066).

Table 11

Analysis of Variance for Mini-Mullen Bursting Strength Results as a Function of Rate of Test and Fabric Type

| Source | degrees of freedom | sum of squares | mean of squares | F-ratio |
|---|---|---|---|---|
| Whole unit | | | | |
| fabric type | 3 | 983,683.65 | 327,894.55 | 0.24 |
| error term | 15 | 20,916,984.78 | 1,394,465.65 | |
| Subunit | | | | |
| rate of test | 1 | 5,878.26 | 5,878.26 | 2.85 |
| rate of test x fabric type | 3 | 4,113.09 | 1,371.03 | 0.66 |
| error term | 15 | 30,961.32 | 2,064.09 | |

A third objective was to determine whether the mini-Mullen or the Hoffman/Turner tester would give more precise results. Precision refers to the the lack of spread of values obtained and is defined by measures of variability (see page 5). Tables 12 , 13, and 14 give values for the percent coefficient of variation for each fabric for each test condition (Table 12); for each fabric type for each test method variation - probe size or Mullen speed - (Table 13); and for each fabric type for the overall Hoffman/Turner and Mullen results (Table 14). Tables 12 and 13 were obtained using total variances; those in Table 14 were obtained using error variances only. In Tables 12 and 13, no clear relationships are evident between results obtained using the Mullen and Hoffman/Turner testers or between results obtained using different Hoffman/Turner probe sizes or Mullen speeds for the fabrics alone, or for the fabrics grouped according to fabric type. However, when the variance is partitioned so that only the error variances are compared (Table 14), it becomes clear that the Mullen tester gives more precise results than the Hoffman/Turner tester.

The general level of precision observed with both testers and all five methods for individual fabrics is not unacceptable, given that a 5 percent coefficient of variation is not unusual with textile fabrics. Percent coefficients of variation for the individual fabrics ranged from 1.27 to 14.58 percent (Table 12) with higher values being associated with certain fabrics, particularly those of the rib type.

Table 12

Percent Coefficient of Variation (% CV)[1] for Each Fabric for Each Hoffman/Turner and Each Mini-Mullen Test Condition

| Fabric[2] | Hoffman/Turner 0.64 cm probe | Hoffman/Turner 0.79 cm probe | Hoffman/Turner 0.95 cm probe | Mini-Mullen (170 ml/min) | Mini-Mullen (17 ml/min) |
|---|---|---|---|---|---|
| A 12 | 2.60 | 3.61 | 5.69 | 1.28 | 1.27 |
| 25 | 4.62 | 4.31 | 3.66 | 4.19 | 2.62 |
| 29 | 3.21 | 3.82 | 4.31 | 5.40 | 3.10 |
| 33 | 6.20 | 5.84 | 7.17 | 4.28 | 4.16 |
| 37 | 5.91 | 6.35 | 6.15 | 3.83 | 1.92 |
| B 04 | 14.58 | 9.34 | 5.57 | -- | -- |
| 06 | 7.61 | 4.66 | 5.11 | 4.80 | 11.73 |
| 14 | 9.58 | 9.14 | 9.88 | 11.28 | 9.94 |
| 49 | 4.09 | 4.22 | 4.27 | 1.92 | 2.29 |
| 50 | 12.20 | 9.28 | 5.93 | 6.44 | 7.93 |
| C 15 | 8.78 | 8.39 | 8.31 | 7.18 | 6.33 |
| 20 | 2.83 | 6.74 | 1.90 | 1.80 | 2.47 |
| 24 | 9.76 | 12.62 | 12.24 | 9.56 | 6.97 |
| 32 | 9.88 | 6.71 | 5.24 | 2.54 | 2.99 |
| 55 | 8.58 | 5.15 | 4.16 | 9.09 | 8.29 |
| D 03 | 3.48 | 4.00 | 3.24 | 3.81 | 2.90 |
| 08 | 8.73 | 8.89 | 9.91 | 5.84 | 6.99 |
| 16 | 5.82 | 4.16 | 3.25 | 2.92 | 3.04 |
| 43 | 2.95 | 3.17 | 3.17 | 2.93 | 2.07 |
| 58 | 2.93 | 2.71 | 3.79 | 2.17 | 1.76 |

---

[1] % CV = 100 x $\frac{SD}{\bar{X}}$ for n = 30 specimens

[2] Fabric group A = tricot knits, fabric group B = rib knits, fabric group C = doubleknit knits, fabric group D = single jersey knits.

--fabric not possible to test

Table 13

Percent Coefficients of Variation for Fabric Types for Each Method of Test for the Hoffman/Turner and Mini-Mullen Testers

| Fabric Type | Percent Coefficient of Variation (% CV)* | | | | |
|---|---|---|---|---|---|
| | Hoffman/Turner 0.64 cm probe | Hoffman/Turner 0.79 cm probe | Hoffman/Turner 0.95 cm probe | Mullen (170 ml/min) | Mullen (17 ml/min) |
| tricot | 1.77 | 1.71 | 1.74 | 1.47 | 1.51 |
| rib | 3.26 | 3.05 | 2.97 | 5.19 | 5.20 |
| doubleknit | 2.65 | 2.95 | 2.78 | 3.02 | 3.04 |
| single jersey | 3.90 | 3.81 | 4.04 | 3.56 | 3.90 |

*% CV = $100 \times \frac{\text{SD of group means}}{\bar{X} \text{ of group means}}$

Table 14

Percent Coefficients of Variation[1] for the Hoffman/Turner and Mullen Methods by Fabric Type

| Fabric Type | Hoffman/Turner Method<br>% Coefficient of Variation | Mini-Mullen Method<br>% Coefficient of Variation |
|---|---|---|
| tricot | 11.84 | 1.22 |
| rib | 8.85 | 3.36 |
| doubleknit | 8.43 | 1.78 |
| single jersey | 4.98 | 2.59 |

[1] See Appendix B for sample calculation

### 4.2.3 Conversion of Results Between Methods

The final objective of this study was to determine if results from each tester could be used to approximate results for the other tester, and similarly, if results for one test condition on either tester could be used to estimate results for other test conditions on the same tester. Tables 15 through 19 are matrices containing Pearson product-moment coefficients of correlation between the different test conditions for the fabrics as a whole (Table 15) and between the different test conditions for the fabrics types (Tables 16 to 19).

All correlation coefficients for the fabrics as a whole were high, positive and significant ($p<.01$). Correlation coefficients ranged from .88 between the Mullen (17 ml/min) and the Hoffman/Turner 0.64 and 0.95 cm probes to 1.00 for the correlation between results from the Hoffman/

Turner 0.79 and 0.95 cm probes and for the correlation between results for the two different rates of test for the Mullen. Coefficients were higher with variations of the same test method (between probe sizes or Mullen rates of test) than those between the testers.

Correlation coefficients for the fabric types varied from high, positive values (.99 to 1.0, $p<.01$), for correlations between results for variations of the same test methods (probe sizes and Mullen speeds) to low positive (.02 to .08) and low negative (-.03 to -.08) correlations between results for the Hoffman/Turner and Mullen testers for the rib type of fabrics. While correlations between results for the Hoffman/Turner and Mullen testers for the tricot, doubleknit and single jersey fabrics were generally high and positive, none were significant at the .01 level.

Table 15

Pearson Product-Moment Correlations† Among the Different Testing Conditions for the Fabrics as a Whole

| Test Condition | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. H/T 0.64 cm probe | | | | | |
| 2. H/T 0.79 cm probe | .99 | | | | |
| 3. H/T 0.95 cm probe | .99 | 1.00 | | | |
| 4. Mullen (170 ml/min) | .89 | .90 | .89 | | |
| 5. Mullen (17 ml/min) | .88 | .89 | .88 | 1.00 | |

†all are significant at the .01 level

Table 16

Pearson Product-Moment Correlations Among the Different Testing Conditions for the Tricot Fabrics

| Test Condition | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. H/T 0.64 cm probe | | | | | |
| 2. H/T 0.79 cm probe | 1.00** | | | | |
| 3. H/T 0.95 cm probe | 1.00** | 1.00** | | | |
| 4. Mullen (170 ml/min) | .97* | .97* | .97* | | |
| 5. Mullen (17 ml/min) | .97* | .97* | .97* | 1.00** | |

*p < .05
**p < .01

Table 17

Pearson Product-Moment Correlations Among the Different Testing Conditions for the Rib Fabrics

| Test Condition | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. H/T 0.64 cm probe | | | | | |
| 2. H/T 0.79 cm probe | .99** | | | | |
| 3. H/T 0.95 cm probe | .99** | 1.00** | | | |
| 4. Mullen (170 ml/min) | -.03 | .03 | -.08 | | |
| 5. Mullen (17 ml/min) | .02 | .08 | -.02 | .97* | |

*p<.05
**p<.01

Table 18

Pearson Product-Moment Correlations Among the Different Testing Conditions for the Doubleknit Fabrics

| Test Condition | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. H/T 0.64 cm probe | | | | | |
| 2. H/T 0.79 cm probe | .99** | | | | |
| 3. H/T 0.95 cm probe | 1.00** | 1.00** | | | |
| 4. Mullen (170 ml/min) | .96* | .92 | .94 | | |
| 5. Mullen (17 ml/min) | .97* | .93 | .95* | 1.00** | |

*p<.05
**p<.01

Table 19

Pearson Product-Moment Correlations Among the Different Testing Conditions for the Single Jersey Fabrics

| Test Condition | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. H/T 0.64 cm probe | | | | | |
| 2. H/T 0.79 cm probe | 1.00** | | | | |
| 3. H/T 0.95 cm probe | 1.00** | 1.00** | | | |
| 4. Mullen (170 ml/min) | .94 | .95* | .95* | | |
| 5. Mullen (17 ml/min) | .95* | .94 | .96* | .99** | |

*p<.05
**p<.01

Table 20

Pearson Product-Moment Correlations† Among the Different Testing Conditions for the Fabrics as a Whole

| Test Condition | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. H/T 0.64 cm probe | | | | | |
| 2. H/T 0.79 cm probe | .99 | | | | |
| 3. H/T 0.95 cm probe | .99 | 1.00 | | | |
| 4. Mullen (175 ml/min) | .96[1] | .95[1] | .95[1] | | |
| 5. Mullen (17 ml/min) | .95[1] | .95[1] | .94[1] | 1.00 | |

†all are significant at the .01 level

[1] rib fabrics excluded from calculation

The low correlations for the fabric types alone suggested that prediction of results between test methods based on knit type could give inaccurate results. A conversion table based on overall results was therefore developed for estimation of results from one tester to another and between test conditions for each tester (Table 21). As no correlation was observed between results for the Hoffman/Turner and Mullen testers for the rib fabrics (Table 17), these bursting strength figures were omitted during calculation of the conversion factors. A new correlation matrix for the fabrics as a whole was first constructed however, to confirm that removal of the rib fabrics from the calculation did not reduce the significance of the resulting coefficients to below the .01 level (Table 20).

Table 21

Conversion Table* for Hoffman/Turner and Mini-Mullen Results with Conversion Values and 99 Percent Confidence Intervals

| Test Method | | Hoffman/Turner 0.64 cm probe | Hoffman/Turner 0.79 cm probe | Hoffman/Turner 0.95 cm probe | Mullen (170 ml/min) | Mullen (17 ml/min) |
|---|---|---|---|---|---|---|
| Hoffman/Turner 0.64 cm probe | = | 1 | .78 ± .02 | .65 ± .05 | .17 ± .03 | .17 ± .02 |
| Hoffman/Turner 0.79 cm probe | = | 1.28 ± .03 | 1 | .83 ± .01 | .22 ± .04 | .22 ± .03 |
| Hoffman/Turner 0.95 cm probe | = | 1.55 ± .04 | 1.20 ± .02 | 1 | .27 ± .05 | .25 ± .04 |
| Mullen (170 ml/min) | = | 6.00 ± .75 | 4.67 ± .60 | 3.89 ± .51 | 1 | .96 ± .03 |
| Mullen (17 ml/min) | | 6.25 ± .79 | 4.87 ± .64 | 4.05 ± .55 | 1.04 ± .03 | 1 |

*multiply figure (kPa) obtained by method noted on top by conversion factor to estimate result (kPa) for chosen method on left (see Appendix D for example).

Values in the conversion table are based on mean ratios of bursting strength values calculated using the two methods in question. To use the table, an average result (kPa) obtained using one method is multiplied by the appropriate mean conversion factor to obtain the expected result (kPa) for the other method (see Appendix D for sample calculation). The 99 percent confidence level associated with each result gives a range within which results may be expected to fall.

The table may be used for conversion of results between test conditions for the Hoffman/Turner tester and between test conditions for the Mullen tester for all types of fabrics (tricot, rib, doubleknit and single jersey), and between testers for the tricot, doubleknit and single jersey fabrics. It should not be used to convert rib knit results between the two testers or considered to be accurate outside the range of strengths of fabrics tested in this project.

## 4.3 DISCUSSION OF RESULTS

### 4.3.1 Mullen Versus Hoffman/Turner Results

Fabric deformations can be viewed in terms of the strains experienced by all individual yarns in the total fabric structure, or in terms of sheet deformation with the fabric viewed as a one or two dimensional continuum. Viewing fabric deformations as a result of what happens to individual yarns is very difficult since fabrics consist of hundreds of yarns composing a matrix of multitudinous yarn interlacements. Modelling a fabric as such a collection of yarns leads to a very large system of equations so analysis becomes very complicated even with computer assistance (Hearle et al., 1980; Shanahan, 1972). Consequently, this approach is not used. A logical alternative is to view the fabric as a continuum and to apply either finite element analysis or sheet deformation theory.

In finite element analysis, governing equations for small representative pieces of a system are developed, each with a limited number of degrees of freedom. Equations for all the small pieces together are then used to represent the total system. This is most conveniently expressed as a series of matrix equations, programmed for computer solution. This approach has not yet been extended however, to deal with very large non-linear displacement, large strain situations as in fabric bursting.

A second approach to looking at fabrics as continua is to examine their behavior in terms of sheet deformation. The large transverse deformations that occur in bursting tests, and the fact that stress/strain relationships are almost invariably non-linear, inelastic and history dependent (Hearle, 1980; Shanahan, 1978) precludes explanation of the deformations in terms of membrane strains, tension membranes, plate and shell theory or in terms of buckling or post-buckling behavior.

A last approach to looking at fabric deformation is through minimum energy analysis. Analysis is based on the principle that fabric structures always assume a minimum energy configuration, regardless of the deformation applied (S. de Jong, 1978). This type of analysis is chiefly concerned with elastic or recoverable mechanisms of fabrics however, and has not been extended to deal with the bursting behavior of fabrics. The theoretical basis for the mini-Mullen giving results of greater magnitude than the Hoffman/Turner mini-probe tester is therefore unclear. Furthermore, there is as yet no theoretical model to predict the "true" bursting strength value of knitted fabrics. It is suggested however that discrepancies in results between the two testers may be related to differences in the areas of fabric under test, and to variations in diaphragm/fabric and probe/fabric frictional effects.

Previous studies have established that an increase in the Mullen aperture diameter results in lower bursting strength results (Norwick, 1975; ISO, 1974; BSI, 1974; Garner, 1967; Lomax, 1961). In this project, a greater diameter of test area (Hoffman/Turner mini-probe actual test diameter = 19.00 mm versus mini-Mullen test diameter = 11.30 mm) was consistently associated with decreased bursting strength results (Table 6, Table 8).

Frictional effects between a given fabric and a rubber diaphragm of the mini-Mullen tester could be expected to be greater than between a probe of the Hoffman/Turner tester and the same fabric due to the nature of their surfaces. The smooth surface of a Hoffman/Turner probe would offer little resistance to passage through a fabric in contrast to the rougher surface of a Mullen diaphragm. The increased force necessary to overcome surface friction between the Mullen diaphragm and the fabric, as opposed to between a Hoffman/Turner probe and the fabric could be expected to result in increased bursting strength results as were noted in Table 8.

### 4.3.2 Probe Size and Hoffman/Turner Results

The increased bursting strength results associated with increased probe size, noted for the foil and fabric testing (Tables 6, 8 and 9) could be expected (Table 1 Whitcomb, 1928, pp. 44). All three probes, being finished to the same smoothness would offer similar resistance owing to surface friction although increased resistance would be expected with increasing probe size with the larger area of contact between the test fabric and the probe. The reason for the greater increase in bursting strength results for rib and doubleknit fabrics than for single jersey and tricot fabrics is unknown.

### 4.3.3 Rate of Testing and Mullen Results

No significant difference was noted between mean bursting strength results obtained using the 170/ml min and 17 ml/min rates of test. Lomax (1961) also found that varying the Mullen pumping rate did not produce significant differences in results.

### 4.3.4 Precision of Results

Given that the chance of finding a fabric defect is increased with an increased area of test, the greater area of fabric test for the Hoffman/Turner tester as compared to the Mullen tester did not result in more precise bursting strength results as expected. This suggests that the assumed area of test may not be the actual area of test and/or that stresses applied by the two methods are nonuniform. During testing it was noted that fabric bursts occurred predominantly in that area of fabric in contact with the tip of the probe or near the centre of the diaphragm. This observation further suggests that stresses experienced by the fabric in both tests were not uniform throughout the area of the specimen.

### 4.3.5 Behavior of Rib Fabrics During Testing

In contrast to other fabric types, no correlation existed between Hoffman/Turner and Mullen bursting strength results for rib fabrics. The rib fabrics also appeared more sensitive to increasing probe size than the single jersey and tricot knits, which suggests further testing of rib knits is warranted, particularly as the Mullen rib results were based on only four fabrics. The different behavior by rib fabrics is not explained by variations in measurements of stitch density, packing factor or extensibility (Table 22).

Table 22

Stitch Density, Packing Factor and Extensibility of Fabrics Tested

| Fabric Type | Fabric Number | Stitch Density[†] (stitches/cm$^2$) | Packing Factor[††] | Extensibility* (cm) |
|---|---|---|---|---|
| tricot | 12 | 244.3 | .28 | 0.58 |
| | 25 | 742.5 | .23 | 2.07 |
| | 29 | 155.0 | .24 | 0.49 |
| | 33 | 267.3 | .26 | 0.46 |
| | 37 | 238.7 | .26 | 0.41 |
| rib | 04 | 84.0 | .14 | 0.94 |
| | 06 | 484.2 | .10 | 1.59 |
| | 14 | 300.1 | .15 | 0.72 |
| | 49 | 314.9 | .17 | 0.66 |
| | 50 | 162.0 | .13 | 0.62 |
| doubleknit | 15 | 180.0 | .13 | 0.55 |
| | 20 | 268.3 | .20 | 0.83 |
| | 24 | 33.6 | .11 | 0.70 |
| | 32 | 177.8 | .15 | 0.59 |
| | 55 | 54.1 | .09 | 0.57 |
| single jersey | 03 | 184.3 | .14 | 0.61 |
| | 08 | 98.6 | .08 | 0.57 |
| | 16 | 425.3 | .07 | 1.07 |
| | 43 | 3479.6 | .09 | 0.66 |
| | 58 | 135.8 | .08 | 0.57 |

[†] stitch density = courses/cm x wales/cm

[††] packing factor = $\frac{\text{fabric density}}{\text{fibre density}}$

* Extensibility = cm extension as measured for fabric selection

### 4.3.6 Practical Considerations In The Use of The Two Testers

A comparison of results obtained using the mini-Mullen tester and the Hoffman/Turner mini-probe tester would not be complete without a discussion of the relative merits of the two testers. Each will therefore be discussed in terms of time involved in use, ease of testing and ease of maintenance.

#### 4.3.6.1 Time To Test

Results in Table 23 indicate that time to test may be substantially increased if the 17 ml/min Mullen is used rather than the 170 ml/min Mullen or the Hoffman/Turner tester with any of its three probes. Time to burst is roughly equivalent for the 170 ml/min Mullen tester and the three conditions of test for the Hoffman/Turner tester; however, additional time is required for the Mullen testing due to the neccesity of changing diaphragms after testing every five specimens.

Table 23

Means[†] and Standard Deviations of Times to Burst (Seconds)

| Fabric Type | Fabric Number | Hoffman/Turner 0.64 cm probe | Hoffman/Turner 0.79 cm probe | Hoffman/Turner 0.95 cm probe | Mullen (170 ml/min) | Mullen (17 ml/min) |
|---|---|---|---|---|---|---|
| tricot | 12 | 2.66 ± 0.10 | 2.71 ± 0.15 | 2.66 ± 0.16 | 2.49 ± 0.15 | 24.21 ± 1.20 |
| | 25 | 9.18 ± 0.48 | 9.29 ± 0.40 | 8.80 ± 0.47 | 2.76 ± 0.23 | 31.04 ± 1.60 |
| | 29 | 2.20 ± 0.09 | 2.16 ± 0.14 | 2.17 ± 0.11 | 2.47 ± 0.20 | 27.05 ± 0.62 |
| | 33 | 2.14 ± 0.11 | 2.10 ± 0.13 | 2.02 ± 0.12 | 2.31 ± 0.18 | 26.11 ± 0.55 |
| | 37 | 2.27 ± 0.09 | 2.26 ± 0.10 | 2.20 ± 0.15 | 2.27 ± 0.13 | 20.15 ± 0.60 |
| rib | 04 | 4.93 ± 0.37 | 5.21 ± 0.35 | 4.66 ± 0.25 | -- | -- |
| | 06 | 8.67 ± 0.38 | 9.07 ± 0.70 | 9.81 ± 0.46 | 2.55 ± 0.25 | 26.19 ± 0.91 |
| | 14 | 2.84 ± 0.17 | 2.91 ± 0.23 | 2.81 ± 0.23 | 2.62 ± 0.16 | 21.96 ± 0.91 |
| | 49 | 7.19 ± 0.30 | 7.38 ± 0.28 | 7.39 ± 0.32 | 2.48 ± 0.11 | 33.88 ± 3.13 |
| | 50 | 2.88 ± 0.27 | 3.00 ± 0.17 | 3.00 ± 0.24 | 2.14 ± 0.20 | 22.14 ± 2.16 |
| doubleknit | 15 | 2.33 ± 0.20 | 2.25 ± 0.15 | 2.26 ± 0.17 | 2.17 ± 0.24 | 20.53 ± 0.77 |
| | 20 | 3.68 ± 0.13 | 3.54 ± 0.19 | 3.77 ± 0.13 | 2.80 ± 0.28 | 25.32 ± 1.78 |
| | 24 | 3.41 ± 0.26 | 3.63 ± 0.33 | 3.54 ± 0.29 | 2.46 ± 0.16 | 22.86 ± 1.13 |
| | 32 | 3.17 ± 0.31 | 3.27 ± 0.41 | 3.30 ± 0.11 | 2.60 ± 0.15 | 22.78 ± 0.68 |
| | 55 | 3.47 ± 0.24 | 3.19 ± 0.28 | 3.24 ± 0.22 | 2.40 ± 0.11 | 22.52 ± 1.27 |
| jersey | 03 | 2.87 ± 0.17 | 2.74 ± 0.24 | 2.58 ± 0.19 | 2.89 ± 0.30 | 23.00 ± 1.71 |
| | 08 | 3.43 ± 0.22 | 3.32 ± 0.21 | 2.94 ± 0.23 | 2.36 ± 0.18 | 21.56 ± 1.02 |
| | 16 | 4.60 ± 0.27 | 4.90 ± 0.42 | 5.18 ± 0.32 | 2.37 ± 0.20 | 21.85 ± 0.73 |
| | 43 | 3.09 ± 0.10 | 3.15 ± 0.15 | 3.13 ± 0.20 | 2.20 ± 0.17 | 25.95 ± 0.58 |
| | 58 | 2.72 ± 0.11 | 2.76 ± 0.07 | 2.56 ± 0.12 | 2.39 ± 0.09 | 20.68 ± 0.68 |

[†] N=30

--Not possible to test

### 4.3.6.2 Ease of Testing

The test procedure is similar for both tests involving placement of the test specimen in the holder, clamping the specimen and executing the test. The Mullen test procedure is complicated, however, by the need to apply a correction factor to compensate for the pressure required to raise the diaphragm alone to its height at specimen burst for every specimen; by the use of Bourdon pressure gauges and by the necessity to prepare composite diaphragms and to change diaphragms after every five specimens.

Difficulties associated with determining the correction factor vary with the Mullen motor used. A deflectometer or device to record maximum distension, is available for use with the 17 ml/min Mullen. Particulars of the test procedure as supplied by the manufacturer, are included in Appendix C. The major problem in using the deflectometer is the difficulty associated with taking the distension reading. The distension at burst is not recorded by a maximum indicating needle, but rather must be read by the operator, at the instant of specimen failure. The operator however, has also to watch the specimen to catch the point of rupture. The pressure gauge must also be watched if specimens are bursting at a pressure near the upper limit of the gauge, to see that overextension of the gauge does not occur.

The deflectometer cannot be used with the 170 ml/min motor for the Mullen because the rate of movement of the indicator needle is too fast. Consequently the ASTM method (page 8) must be used. This method does not require repeating the test procedure without the test specimen to obtain the distension measure. It does however, require taking two pressure measurements.

The system of pressure measurement employed does not facilitate testing. Gauge divisions are coarse (40 psi on a 1000 psi gauge); and readings are operator dependent in that maximum pressure at burst is a function of the ability of the operator to read the gauge accurately. Also, there is no safety pressure mechanism to avoid overextending and hence damaging the gauges.

Preparing composite diaphragms and changing the diaphragms after every five specimens is time consuming.

#### 4.3.6.3 Ease of Maintenance

Maintenance procedures for the Mullen are somewhat more complex than those for the Hoffman/Turner tester. The Mullen gauges, according to the manufacturer's specifications, require a monthly static and dynamic calibration check resulting in increased down-time and maintenance costs for the tester.

# Chapter V

## SUMMARY AND CONCLUSIONS

Results obtained using two mini-bursting strength testers: the mini-Mullen and the Hoffman/Turner mini-probe tester were compared, first for gross differences between results for the two testers, then using analysis of variance techniques, for differences between results for the various test conditions available for each tester. These included two pumping rates for the Mullen (170 ml/min and 17 ml/min) and three probe sizes (0.64, 0.79, and 0.95 cm) for the Hoffman/Turner tester. The purposes of the comparisons were to determine if the two testers gave equivalent (not significantly different at the .01 level) results, if the various conditions of test for each tester gave equivalent results, if one tester gave more precise results than the other and finally, to develop a conversion table for approximate conversion of results from one method to another.

Twenty fabrics representing a range of extensibilities were selected for testing using a purposive sampling technique. The twenty consisted of five fabrics of each of four knit types: tricot, rib, doubleknit and single jersey. Thirty specimens were selected from each fabric for testing by each test condition. Bursting strength measurements for the mini- Mullen were determined according to ASTM D3786-80a; measurements for the mini-probe tester were determined according to a procedure outlined by Hoffman and Turner (1975). Initial testing with standard foil indicated that results obtained using the two test methods were reproducible. Results of final fabric testing are described in the following paragraphs.

The Mullen tester at pumping rates of both 17 ml/min and 170 ml/min consistently gave results of significantly greater magnitude than the Hoffman/Turner tester irrespective of whether results were obtained using the 0.64, 0.79, or 0.95 cm probe. Results for the Hoffman/Turner tester were probe size dependent, with increased probe size resulting in significantly increased bursting strength values for all fabrics. Mullen results did not vary significantly between the 17 ml/min and the 170 ml/min pumping rates. Results did not differ significantly between fabric types although as probe size increased, mean bursting strengths showed greater increases with the rib and doubleknit types than with the single jersey and tricot types. It was not possible to test one rib fabric of low count and high extensibility with the Mullen.

The relative precision of the two testers was established by comparison of percent coefficients of variation for the knit types for the Hoffman/Turner and Mullen testers. Both testers gave an acceptable level of precision, although mini-Mullen tester was found to give more precise results than the Hoffman/Turner mini-probe tester.

Pearson product-moment coefficients of correlation were calculated between the different test conditions for the fabrics as a whole and between the different test conditions for the fabric types as a basis for determining whether it was feasible to develop a conversion table for predicting results for one test condition, given the results of another. High, positive correlations were found between Hoffman/Turner and Mullen results for the twenty fabrics as a whole. Correlation coefficients for the fabric types alone varied from high positive values between methods for the same tester (probe sizes and Mullen speeds), to low positive and low negative correlations between results for the Hoffman/Turner and Mullen testers. The low correlation results for the fabric types (particularly the rib) as a whole suggested that conversion of results between test methods based on knit type could give inaccurate results. A conversion table for estimation of results between conditions of Hoffman/Turner and Mullen results was therefore developed based on overall fabric results. The conversion table should not be used with rib fabrics to estimate results between the two testers as the low figures obtained for this fabric type suggest that prediction is not possible. Nor should the table be used to convert strength values outside of the range of values for the fabrics tested in this study.

## 5.1 IMPLICATIONS

Results of this study have implications for those involved in the quality control testing of vascular prosthesis, as well as for those involved in standards specifications for strength testing of vascular prostheses. Results indicate that care is necessary in stating mini-diaphragm and mini-probe bursting strength results. The fact that the Hoffman/Turner and mini-Mullen testers give different results suggests that the value of the bursting strength of knitted fabrics can only be defined in terms of a specific test method. Similarly, the fact that the use of the three probe sizes for the Hoffman/Turner tester gave very different results means that probe size must be given when stating bursting strength values.

A low fabric count/high extensibility combination may preclude testing some fabrics with the Mullen. The fact that the Mullen tester gave more precise results than the Hoffman/Turner tester means that fewer specimens would be needed to achieve the same degree of confidence in results as with the Hoffman/Turner tester, and that smaller differences can be detected with the Mullen tester.

An approximation of results from one test condition of the Hoffman/Turner or mini-Mullen tester is possible, given the results of another test condition, although the procedure is not recommended for rib fabrics.

## 5.2 SUGGESTIONS FOR FURTHER RESEARCH

Replicating the study with a larger number of fabrics in each group would be useful, as the findings from this project suggest that bursting strength behavior varies with knit type. Increasing the number of fabrics and the range of fabric strengths tested in the four types would result in increased confidence in results obtained for various test conditions, and for the rib type in particular.

A better understanding of the possible influence of various test parameters on Hoffman/Turner results is desirable. For example, the influence of area of fabric under test could be assessed if several new lower clamping plates were constructed each with an O-ring of different diameter. The influence of frictional characteristics of the Hoffman/Turner probe could be assessed by coating probes with materials of varying frictional characteristics. The influence of probe end shape could be assessed by varying the shape from hemispherical.

Further research to improve the Mullen test procedure is recommended. Work is needed to find a stronger diaphragm of unit thickness, to devise a safety mechanism to avoid over-pressuring and damaging gauges, and to simplify measurement and recording of the maximum pressure perhaps through the use of a digital pressure read out.

An understanding of the theoretical models underlying the two bursting strength procedures is desirable. Further work in this area is continuing at the University of Manitoba.

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# APPENDIX A

Table 3

Fabrics Grouped According to Type and Average[†]
Extensibility (cm)

| Tricot | Single Jersey | Rib | Doubleknit |
|---|---|---|---|
| 0.41 (37)[††] | 0.45 (07) | 0.53 (45) | 0.55 (15) |
| 0.46 (33) | 0.47 (02) | 0.54 (52) | 0.57 (40) |
| 0.49 (29) | 0.50 (53) | 0.62 (50) | 0.57 (55) |
| 0.51 (18) | 0.53 (48) | 0.66 (49) | 0.58 (28) |
| 0.53 (23) | 0.54 (01) | 0.69 (44) | 0.59 (32) |
| 0.55 (39) | 0.54 (41) | 0.72 (14) | 0.61 (11) |
| 0.56 (13) | 0.54 (58) | 0.88 (05) | 0.64 (35) |
| 0.58 (12) | 0.56 (46) | 0.94 (04) | 0.66 (36) |
| 0.60 (31) | 0.57 (08) | 1.47 (51)** | 0.69 (34) |
| 0.62 (38) | 0.58 (57) | 1.59 (06)** | 0.70 (24) |
| 1.29 (56)* | 0.60 (47) | | 0.73 (26) |
| 1.64 (42)* | 0.61 (03) | | 0.74 (21) |
| 2.07 (25)* | 0.65 (54) | | 0.76 (27) |
| | 0.66 (43) | | 0.80 (17) |
| | 0.67 (19) | | 0.80 (30) |
| | 1.07 (16)** | | 0.83 (20) |
| | | | 0.85 (22) |
| | | | 0.91 (09) |
| | | | 0.93 (10) |

[†] Average of 2 specimens.

[††] Numbers in brackets represent the fabric number.

*Fabrics containing elastic yarns.

**Fabric contained a highly crimped yarn to impart stretch.

# APPENDIX B

## Sample Calculation of Percent Coefficient of Variation

for: Mullen Method
tricot type fabrics

| Source | degrees of freedom | sum of squares | mean of squares | F-ratio |
|---|---|---|---|---|
| Mullen methods | 1 | 8743.849 | 8743.849 | 16.42 |
| Tricot fabrics | 4 | 12947575.024 | 3236893.756 | 6077.94 |
| error | 4 | 2130.256 | 532.564 | |
| total | 9 | 12958449.129 | | |

grand mean = 1892.210

NOTE: $\% \; CV = 100 \times \frac{SD}{\bar{\bar{X}}}$

$$100 \times \frac{\sqrt{ms}}{\text{grand mean}} = \frac{\sqrt{532.364}}{1892.21} = 1.22\%$$

# APPENDIX C

## OPERATING INSTRUCTIONS FOR DEFLECTOMETER ATTACHMENT MODEL "A" OR JUMBO TYPE TESTER

### Description

The Deflectometer consists of an indicating gauge with actuating rod mounted on the clamp screw of the tester. The actuating rod extends down through the hollow center of the clamp screw and rests on the center of the sample to be tested. The dial of the gauge is graduated in .001 of an inch and will indicate a total rise of 1 inch of the actuating rod.

### Operation

1. Place the sample to be tested under the tripod and clamp in the usual manner. The indicating gauge rotates with the hand wheel and the position of the gauge face relative to the operator is dependent on the thickness of the sample under the clamp. It may be adjusted by loosening the knurled set screw on the gauge mount and rotating the gauge so that the dial faces the operator. On succeeding tests on the same material the dial will always face the operator after clamping.

2. The foot of the actuating rod should rest on the center of the sample. The operator will observe that the actuating rod extends up through the indicator and emerges at the top to form a knurled handle. Pull this handle or knob straight up a distance of 1/4 inch and release it. The rod should drop back instantly to its original position. Repeat 3 or 4 times, observing the position of the needle on the dial after the rod drops back. If it always stops at the same point, it indicates that the foot of the rod is resting on the sample as it should and is free to rise with the sample.

3. Loosen the dial stop knob on top of the indicator and rotate the dial to a position where the pointer coincides with zero on the dial.

4. Start the test and take a reading when the desired pressure has been applied to the sample. Read the small dial first (which indicates the rise in tenths of an inch) then read the large dial to obtain the second and third digits. For example: The small pointer on 3 and the large pointer half way between 7 and 8 indicates that the rise has been .375" or 3/8".

Since the purpose of the Delfectometer is to determine the distention of the sample at the bursting pressure or any other predetermined pressure it is necessary to take a reading before bursting actually takes place to be of any value. It is, therefore, advisable to make a few preliminary tests to determine the average bursting pressure of the sample. The Deflectometer can then be watched closely to observe the maximum rise previous to the burst.

## Care of the Deflectometer

The Delfectometer is necessarily a delicate instrument and should be handled carefully. The actuating rod should never be forced beyond its normal travel and the rod must be perfectly free at all times to be raised by the diaphragm or lowered by gravity.

# APPENDIX D

## An Example of Use of the Conversion Table

Given: A Mullen (17 ml/min) value of 1000 kPa for a given Fabric A

Required: an estimate of the bursting strength value that would be obtained using the Hoffman/Turner mini-probe apparatus with the 0.95 cm probe for the same fabric A.

Procedure:

(1) Test methods are noted along the top of the table and along the left side of the table. Locate the column under the row heading of: Mullen (17 ml/min).

(2) Move down this column until the value corresponding to the column heading: Hoffman/Turner 0.95 cm probe is located.

(3) Record this value. It is .25 ± .04.

(4) Calculate the expected values for the Hoffman/Turner test as follows:

- expected value (kPa) = Mullen (17 ml/min) value (kPa)
  x conversion factor
  = 1000 (.25)
  = 250 kPa
- .99 confidence interval (kPa) = 1000 kPa (.25 ± .04), 1000 kPa (.25 ± .04)
  = 1000 (.21), 1000 (.29)
  = 210 kPa, 290 kPa