A teletype-computer “time-sharing” concept has been applied to calculation and print-out of standard spirometric measurements. The factors which conditioned development of the software program and selection of hardware, and the steps involved in making the entire system operational are described. The simplicity, flexibility and the low cost and space requirement of this approach are outlined. Data derived from our laboratory using these methods are presented. It is concluded that variations on this basic theme can bring spirometric testing within the reach of a broad range of medical facilities and enhance the detection and management of patients with respiratory disease.

Pulmonary spirometric testing provides information which can contribute to improved medical care in several ways. In the hospital, it can aid in the management of patients considered for major surgery, particularly cardiopulmonary surgery. In the physician’s office, it can provide objective data regarding the presence and extent of obstructive lung disease in his patients, permitting earlier institution and better evaluation of therapy. In mass screening programs, spirometry can guide public health efforts to control respiratory diseases and supply insight into their natural history.

Yet the broad potential of spirometric testing has not been realized to date. A number of practical problems have hampered its general application. Valid testing has required rather expensive special apparatus that appeared complex to operate. Even more limiting was the fact that, once the tests were performed, a number of calculations were required. Next, the data needed to be transcribed into some permanent record form. Finally, an accurate diagnostic formulation had to be made by or transmitted to the physician.

This entire process required expertise and time not available on a full-time basis in most hospital-clinic facilities, and even less so in a busy practitioner’s office. Furthermore, even where such facilities have been available, the time involved from request for study to receipt of the information often was appreciable. Obviously, detailed spirometry cannot be imposed as a diagnostic or preoperative routine if several days might elapse before the results are available.

These considerations led us to explore the marriage of computer technics with routine spirometric testing. Computer methodology has been applied by others to spirometry, but the major emphasis of prior efforts has been upon simple screening tests.1-3 Our aim was to develop an approach which would provide for more detailed spirometric evaluation and easy, low-cost application to a broad spectrum of medical facilities in the community.
short, the goal was to adapt computer technology so that spirometric testing could achieve wide application within the framework of existing facilities.

**Methods**

First, resources for carrying out spirometric studies in area medical facilities were reviewed. This review indicated that many facilities had direct-recording spirometers, plus ancillary equipment for determination of residual volume. Therefore, the most effective initial approach appeared to be the development of a method which permitted adaptation of computer techniques to existing equipment.

A computer ("software") program was developed to be compatible with the spirometric apparatus used for routine studies at the Georgetown University Hospital. This apparatus consisted of a double-bell spirometer (Pulmotest), adapted to carry out determination of the functional residual capacity by the closed circuit helium method\(^4\) and the single breath diffusing capacity for carbon monoxide.\(^5,6\)

Accepting this spirometric system as a prototype, the data routinely obtained was next examined. The following measurements were included in our standard spirometric report: (1) static lung volumes: vital capacity (VC), tidal volume (TV), inspiratory and expiratory reserve volumes (IRV, ERV), functional residual capacity (FRC), residual volume (RV), total lung capacity (TLC) and residual volume/tot al lung capacity ratio; (2) dynamic lung volumes: forced expiratory volume (1 second) in percent of forced vital capacity (FE\(V_1\)); maximum mid-expiratory flow rate over the 25 percent to 75 percent and 50 percent to 75 percent portions of the forced vital capacity (MMEF\(_{25-75}\) and \(_{50-75}\)); maximum voluntary ventilation (MVV); (3) miscellaneous observations such as the respiratory rate, minute ventilation, oxygen consumption, respiratory equivalent (minute ventilation/oxygen consumption per minute); (4) the single breath carbon monoxide diffusing capacity (DC\(_{CO}\)). Certain of the measurements listed under (1) and (2) were also routinely repeated after bronchodilator aerosol in patients with evidence of expiratory obstruction.

The steps between performance of the test and appearance of a formal report were next analyzed. These steps included: (1) recording of measurements from the spirometric tracing and from the helium and carbon monoxide meters; (2) conversion of the raw measurements to cubic centimeters, seconds and percentages; (3) calculations of the static and dynamic lung volumes, DC\(_{CO}\), respiratory equivalent, and oxygen consumption; (4) application of formulae for appropriate correction to BTPS or STPD; (5) calculation of "normal values" for the particular patient; (6) recording of final calculations on a data sheet; (7) checking and interpretation of final data by a physician; (8) typing of the data in final form in multiple copies by a secretary.

A time analysis indicated that these tasks required a minimum of 30 to 40 uninterrupted minutes in the hands of a highly skilled technician-physician-secretarial team. In the above sequence, there were multiple opportunities for error in calculation or transcription of data, and also for delays.

**Software Computer Program**

Based on the analysis described above, a computer "software" program and a "hardware" concept were developed. A "program" was defined as a collection of algorithms for solving a specific problem; a "concept" was defined as the definition of a functional computer system. The concept of computer technics to existing equipment.
to the ordinate of a percent helium (ordinate) versus time (abscissa) plot. With this value, the FRC is obtained from a calibrated helium dilution curve developed from in vitro studies with the spirometer. All of these steps were designed into the program, including provision for insertion of the new calibration curve data.

The software program also included provisions for calculating “percent normal” (patient value/predicted “normal” value × 100) values where such calculation might prove meaningful. Finally, the program included provision for recording of patient and location identifier material.

The reporting format was designed to permit easy reading and comparison of predicted values with patient data, while conforming to hospital regulations of paper size for inclusion in charts (Fig 1).

Hardware

Requirements for practical hardware implementation of the program were rather stringent. The major features of this aspect of the integrated computer-spirometric system had to include: (1) easy operation by someone with limited training; (2) rapid print-out of the data in multiple copies suitable for direct insertion into a patient's hospital chart or for submission to a physician (Fig 1); (3) limited space requirements for the computer input-output terminal; (4) eliminate the need for an "in-house" computer; (5) low cost per patient, even on a limited use basis.

These requirements were all met by a hardware system composed of a standard teletype installation with punch-tape capability. This teletype granted approval access to one of two "time-sharing" computers. One computer was located in Bethesda, Maryland; the other in Cleveland, Ohio. Both computers were medium to large-scale type, high capacity systems capable of readily handling the rather long and complex pulmonary spirometric programs.

Having implemented the basic software with suitable hardware, the last steps were adoption of a format for recording of data, a simple instruction manual for use of the teletype-computer system, and instruction of technicians-physicians in its use.

RESULT

The final product of the system is presented in Figure 1. Four copies of this printout are made on each teletype run. A punch tape of the data appearing on the final form is also obtained. This permits additional four-copy printouts to be obtained rapidly at any time.

Patient identifier material is printed out above. Space is preserved at the upper right for imprint of the identifier “plate” used for in-patients at our hospital. Names of the various spirometric measurements appear in the first column; predicted values for the patient, in the second. Data obtained without medication are in the third column with “% normal” calculations in the fourth. Data obtained after administration of bronchodilator aerosol is in the fifth column and “% normal” postdilator values in the last column.

Time Comparisons

Comparisons were made between the computer system and the former method in terms of the time elapsed from patient study to completion of the report form. It was found that our experienced technicians required 25-30 minutes per patient to produce final calculations and provide a legible copy for the physician in the laboratory to check and review. These technicians average six years of experience in a pulmonary function laboratory on a full-time basis and were using a high-speed desk calculator for their computations.

In addition, a minimum of five minutes of secretarial time were required to produce an original and three carbon copies of the data. Again, it should be noted that our secretaries have had extensive experience with the rather complex insertions of data required on the former report form.

The computer system, on the other hand, required an average of 15 minutes of technician time and no secretarial time. Printout of the data required five minutes, but needed no personnel time.

Cost Analysis

By the methods previously used, the cost of spirometric studies (from completion of the tests to delivery of the final typed data) approximated $3.50 per patient. This figure excludes the costs involved in performing the tests themselves, and the physician time required for reading and diagnostic formulation.

The cost per patient with the computer approach depends on the volume of patients studied, since certain fixed costs are involved (monthly rental of the teletype and a minimum computer charge). For instance, if ten patients per month were studied, the cost would be $20.00 per patient. With 30 per month, the per patient cost would approximate $7.30. With higher volumes, cost would reach an irreducible minimum of approximately $4.50 per study at current computer-teletype costs.

Accuracy of Data Provided

In ten consecutive men patients and ten consecutive women, spirometric data were calculated by the technicians according to our prior methods, and by the computer program. As indicated in Tables 1 and 2, no significant differences were noted between the two methods on a statistical basis. Indeed, where individual differences were encountered, it was found that these differences invariably resulted from a calculation, recording, or typographic error.

DISCUSSION

In theory, application of computer methods to certain measurements in medicine, such as pulmo-
**Computer Program for Spirometric Testing**

**Table 1**—Results of hand-calculated versus computer calculated data in 10 men. None of the differences was significant by the “t” test (N.S. = not significant). Values given are group means ±1 standard deviation.

For abbreviations used, see text.

<table>
<thead>
<tr>
<th></th>
<th>Hand Calculation</th>
<th>Computer “t”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vital capacity (ml)</td>
<td>4,259±1,528</td>
<td>4,301±1,542</td>
</tr>
<tr>
<td>Residual volume (ml)</td>
<td>1,577±635</td>
<td>1,558±643</td>
</tr>
<tr>
<td>Total lung capacity (ml)</td>
<td>5,858±1,460</td>
<td>5,859±1,469</td>
</tr>
<tr>
<td>RV/TLC ratio (%)</td>
<td>28±14</td>
<td>28±15</td>
</tr>
<tr>
<td>MVV (Liter/min.)</td>
<td>98±54</td>
<td>110±50</td>
</tr>
<tr>
<td>FEV₁ (%)</td>
<td>69±18</td>
<td>69±18</td>
</tr>
<tr>
<td>MMEF, 25–75 (1/sec.)</td>
<td>3.0±1.8</td>
<td>3.0±1.8</td>
</tr>
<tr>
<td>ERV (ml)</td>
<td>1,413±722</td>
<td>1,427±729</td>
</tr>
<tr>
<td>IRV (ml)</td>
<td>2,103±2,104</td>
<td>2,123±2,104</td>
</tr>
<tr>
<td>TV (ml)</td>
<td>802±217</td>
<td>810±220</td>
</tr>
<tr>
<td>Vo₂/(ml/min.)</td>
<td>294±41</td>
<td>297±40</td>
</tr>
<tr>
<td>Resp. Eq.</td>
<td>39±16</td>
<td>39±16</td>
</tr>
</tbody>
</table>

Another barrier to computer application has been the consideration that many hospitals, clinics and physicians already have some form of spirometric testing system. There is valid objection to consideration of scrapping an existing system in favor of another particularly suited to a given computer program or specially adapted for automatic computations. The approach we have described can easily be adapted to existing equipment for spirometric measurement. Adaptation becomes a function of the software (program) rather than the spirometric equipment. A brief visit by a programmer can assess the performance characteristics of the spirometric device available; appropriate revisions in the program then can be made. This program is designed to make such adjustments a simple matter. Simple ruler measurements in millimeters are still all that is required.

The flexibility of the system extends to other
were brought in. Alternatively, results could be what deceptive. The computer approach provides
laid acceptably for 48 hours.
in instances where receipt of data might be de-
rangements can be designed. For example, to
puter" methods
nics. With limited instruction, such personnel can
scribed.
the appropriate program. Printed reports would be
available the next morning when new tracings
be quickly absorbed by an active spirometric test-
ing program.
The real and potential benefits of the type of
spirometric system described are multiple. In our
own laboratory, it has made possible better utiliza-
tion of highly experienced technical personnel by
freeing them from a large volume of repetitive cal-
culations. The shortage of skilled cardiopulmonary
technologists makes this a major gain in terms of
other patient care-research programs. Our techni-
cians have greeted the new system with enthu-
siasm.
In hospitals and clinics where the case load is
limited, spirometry is often assigned on a part-time
basis to technicians trained primarily in other tech-
nics. With limited instruction, such personnel can
acquire the skill needed to operate the system de-
scribed.
Obviously, a variety of flexible community ar-
rangements can be designed. For example, to ser-
vice multiple small clinics and offices, one technician
could be provided to make the necessary measure-
ments from the spirometric tracings, and call up
the appropriate program. Printed reports would be
available the next morning when new tracings
were brought in. Alternatively, results could be
provided verbally by telephone or delivered by mail
in instances where receipt of data might be de-
layed acceptably for 48 hours.
The cost comparisons between "hand" and "com-
puter" methods provided above are valid, but some-
what deceptive. The computer approach provides
error-free data each time. This is not the case in the
hand calculation-typing approach in which errors
may lead to recalculation and retyping. Further-
more, the computer actually supplies more data
than we formerly obtained by hand calculation (for
example, "% normal" values for pertinent items).
Finally, even in a busy laboratory-secretarial en-
vIRONMENT, the brief technician time needed to ac-
quire and enter the data is always available,
assuring rapid availability of the finished report.
There is no "pile-up" of studies awaiting calculation
or typing.
Whatever the ultimate details of its application,
the computer-spirometer approach described above
already has demonstrated that accurate spirometric
data can be obtained rapidly by many physicians
who regarded it as beyond reach. Routine preoper-
ative spirometry in certain surgical patients has
always been as meaningful as routine electrocardi-
goingraphy. Now spirometric data can be as easy to
obtain. Physicians need no longer wait days for the
results of such tests requested on patients on a re-
ferral basis. Broad screening programs are within
the reach of interested groups with limited financial
resources. Inclusion of such testing as part of rou-
tine, complete physical examinations is also feasible.
In short, a flexible software program plus tele-
type-computer "time-sharing" facilities should al-

ter spirometry to achieve the use it has deserved
in improving the detection and care of patients
with respiratory disease.
In the future there will be even more rapid ap-
proaches to spirometric testing. Spirometers them-
selves and other analyzers involved in the basic
measurements can be adapted to provide electrical
outputs directly to magnetic tape. The tape can
then be analyzed by a computer program similar
to the one we have described, including retention
of the "time-sharing" concept. Another logical ex-
tension would be automated analysis of the outputs
directly, without a tape intermediary. Both the
tape and direct approaches would not only enhance
the accuracy and consistency of the input by elimi-
nating the initial data measurement step, but also
result in additional time-saving. However, adaptation
of existing spirometric devices (or acquisition of
new ones), purchase of taping equipment, develop-
ment of tape to computer conversion programs
and provision for "on-line" analysis currently in-
volve financial and personnel requirements which
are impractical on a broad scale. The system we
have described allows spirometry to gain a place
in the community now.
DYSPNEA, CYANOSIS AND APPARENT DEXTROCARDIA

Neonatal mortality rate, 23.4 for each 1,000 birth in 1966, seems unduly high compared with pertinent data from some of the other civilized countries. One of the possible contributory factors to asphyxia of the newborn may be the lack of prompt diagnosis of congenital diaphragmatic hernias. The latter was first recognized by Riverius in 1869. These hernias occur with greater frequency on the left side than on the right. Large hernia of the left lung by herniated loops of small intestine, a consequence of ventilatory deficiency due to compression of the left lung through the foramen of Bochdalek and cyanosis are associated with respiratory acidosis as well as disturbance of descent of the primitive components of the diaphragm or incomplete fusion of its diverse parts may lead to its structural defects. On physical examination, one finds limitation in motion, unusually tympanitic percussion note and absent breath sounds on the left side, and cardiac dulness and apex beat displaced to the right. Diagnosis is established by radiographic examination of the chest. Roentgenograms are taken with the patient in various positions. X-ray films reveal multiple, small sinuous translucent areas, corresponding to gas-filled intestinal segments, particularly in the lower one-half of the thoracic cage and/or abnormal shadows at the cardiophrenic angle. In addition there are findings characteristic of atelectasis of the left lung, shift of the trachea beyond the midline, emphysematous or partially compressed right lung and displacement of the heart to the right. By identifying the contour of the diaphragm, one can distinguish diaphragmatic hernia from eventration. Immediate surgical intervention with restoration of the normal location of abdominal organs is mandatory in neonates with the diagnosis of Bochdalek's hernia. Normal lung function can be expected in from three days to three weeks postoperatively, with the aid of appropriate supportive measures.

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