DIAGNOSTIC APPLANATION TONOMETRY

For IBM Compatible Computers

Version 1.0

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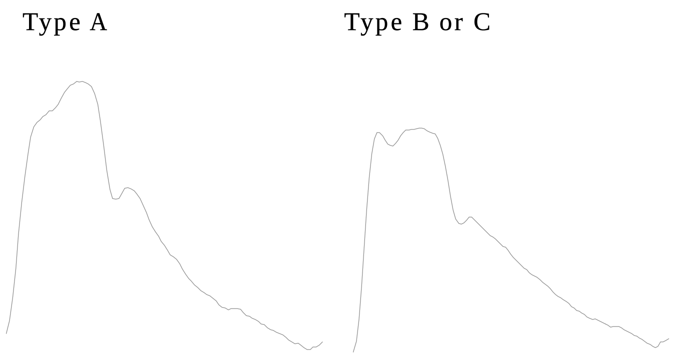
INTRODUCTION

Applanation tonometry quantifies the age old practice of palpating the peripheral pulse, and represents a substantial technical improvement over the mechanical sphygmographs (Marey, Mahomed, Dudgeon, and Mackenzie-Lewis) used some hundred years ago. Previously, information in the contour of the arterial pressure wave remained hidden (a) because of the artefacts in recorded tracings (b) because of inability to digitize and process the waves and (c) through lack of theoretical basis to analyze the waves.

The use of applanation tonometry in assessing changes in the peripheral pulse contour with ageing (see figure) and in response to different therapeutic agents has been validated previously. In addition, generalized algorithms have been developed and validated to relate changes in peripheral pressure contour to changes in central pressure contour.



The typical waveforms in central aorta. Type A pulses have a distinct shoulder in late systole which augments the systolic pressure and seen mostly in elderly patients. Type B or C pulses are seen in young patients where no augmentation in the pulse can be observed. Although these descriptions are categorical there is a continuos spectrum of pulses can be observed due to different degrees of reflected waves present in the composite pulse. Augmentation index describes the amount of reflected wave in the pressure pulse (adopted from Murgo et al (1980). Circulation 62:105-116).

Diagnostic applanation tonometry **(DAT)** is a system consisting of an IBM compatible PC, a Millar Applanation Tonometer and user friendly software. The system has been developed by Dr Mustafa Karamanoglu as part of his PhD thesis. It is a computerised diagnostic tool for the clinical assessment of several pulse indices in real time, eliminating the time consuming manual analysis. The **DAT** system is based on the acquisition of pulses from a peripheral upper body site (which can be a radial, carotid, brachial, axillary or subclavian artery) by applanation tonometry and synthesis of the corresponding ascending aortic pressure wave. The analysis of pressure waves measured invasively or non-invasively by other methods can also be analysed similarly. Synthesis of the ascending aortic wave is possible on account of constancy of transfer function for pressure wave transmission in the upper limb of humans.

After synthesising the ascending aortic pulse, relevant physiological parameters are derived automatically. This information can assist the clinician to evaluate the coupling between the systemic circulation and left ventricle, and can enhance substantially the relatively limited information available from the use of sphygmomanometer.

Other features of the system are:

- On-line analysis
- Database for patient files
- Report function

This manual assumes you have basic knowledge on operations of your computer system. The manual is organised as follows:

- Chapter 1 Installation of the **DAT** software
- Chapter 2 An overview of the **DAT** System
- Chapter 3 Patient information input form
- Chapter 4 Acquisition of the arterial pulses
- Chapter 5 Generation of a report
- Chapter 6 Advanced users
- Chapter 7 Technical guide to operations
- Chapter 8 Answers to common questions asked about how to get most from the **DAT**
- Chapter 9 Guide to common causes of trouble and how to fix them

If you have any queries about the inner workings of the software or if you need further information about the system, please feel free to correspond to the address given in the front page

CHAPTER 1

GETTING STARTED

Before using the **DAT** software, make sure you have the following hardware and software.

Hardware Requirements

- An IBM-AT personal computer or compatible with math-co-processor
- A monochrome or colour monitor with Hercules or EGA/VGA graphic card
- At least 512 Kilobytes of free memory
- A hard disk of a capacity of 20 MB or more
- A Millar Tonometer System or other accurate device for peripheral pulse registration which outputs 1Volts/100 mmHg
- A 12 bit A/D system with optional D/A channels with at least 500 Hz acquisition rate
- A dot matrix or laser printer recognising PostScript or PCL languages

Software Requirements

The **DAT** software runs on the Version 3.0 or later versions of the PC-DOS or MS-DOS operating system.

Installing the Data Acquisition Boards

Supported data acquisition hardware is Data Translation (Data Translation, Inc. Mass.) boards:

DT2801, DT2801-A, DT2801/5716, DT2805, DT2805/5716, DT2808, DT2818

Install the acquisition board as suggested by the manufacturer and set the base address of data acquisition system to 2EC (Hexadecimal).

Attach pressure waveform input cable to channel 0 (zero) of A/D board. Optinally you may attach channel 1 of the A/D board to Lead II of an ECG or a reference trigger source to time the onset of the pressure wave.

Installing the Software

This section describes how to install the **DAT** system onto your hard disk. You only need to install the system once.

Before using **DAT** for the first time, please follow these steps:

- *Start the computer system*

When DOS displays its prompt, place the **DAT** diskette into drive A. If the prompt is not **A:** type **A:** <**Ente**r>. The system will then display the **A:** prompt.

- *Type **DAT I** and press <**Enter**>.*

The **DAT** displays the following prompt:

Drive: [C]

- *Type the letter identifying the hard disk where you want to install the **DAT** system and press <**Enter**>. To accept the current value Drive C, simply press <**Enter**>. The **DAT** will display the following prompt:*

Directory: [\DAT]

- *Type the name of the directory where you want the **DAT** to place the **DAT** software. If the directory does not exist, **DAT** will create it for you. To install the **DAT** system in the root directory, simply press <**Enter**>.*

DAT then asks the hardware information by issuing the following prompt:

Printer types:

1=9 pin dot matrix

2=24 pin dot matrix

3=HP LaserJet

4=Postscript

Enter Number:

- *Type the relevant number and press <**Enter**> to install the appropriate printer driver.*

Printer Port:

1=LPT1

2=LPT2

3=COM1

4=COM2

5=FILE

Enter Number:

- *Type the relevant number and press <**Enter**> to install the appropriate printer port.*

A/D Board type:

1=DT280X series

2=Other

3=Nil

Enter Number:

- Type the relevant number and press <**Enter**> to install the appropriate signal acquisition driver.

Finally **DAT** asks for confirmation

CONFIRM. Do you wish to install DAT? (Y/N) [N]

- Type **Y** and press <**Enter**> to install the system. **DAT** will inform you when the installation is complete and will return you to the DOS prompt.

Please note:

1. As with all applications running under DOS, **DAT**'s performance can be **enhanced** if you specify BUFFERS=20 and FILES=20 in the CONFIG.SYS configuration file. Refer to your Disk Operating System manual for information on the BUFFERS and the FILES commands.

2. If you make a mistake while answering the **DAT** prompts, press <**Control-C**>. You will then receive the DOS prompt which will allow you to re-start the installation process again.

3. As different drivers for different hardware become available these would be included in future upgrades of the software.

Executing the Program

To use the **DAT** program, make sure you are in the directory where the **DAT** files were installed, then type

- ***DAT** and press <**Enter**>.*

CHAPTER 2

OVERVIEW

What is DAT ?

DAT is a newly developed computerised diagnostic tool for the clinical assessment of pulse indices. This system is designed to determine central haemodynamic indices from peripheral pressure wave measurements using applanation tonometry. The system can also be used with invasively determined pressure waves from the radial or brachial artery.

Theory of Operation

The pressure pulse contains far more information than just peak and minimal values (systolic and diastolic pressures). It also contains information resulting from ventricular/vascular coupling. However, the information available from the pulse in peripheral arteries does not correlate well with the centrally derived haemodynamics because of the distortion caused by wave propagation to the periphery. **DAT** uses a convolutional algorithm to calculate central aortic pressure, thereby central indices to be obtained from the pulse recorded in peripheral arteries of the upper limb.

Features of DAT

- A pressure wave acquisition system (currently Millar tonometer system).
- An on-line analysis feature.
- A comprehensive report system.
- A database system for accessing patient information and their records.
- A contextual on-line help system.
- A command line interface to execute commands at the DOS prompt.

CHAPTER 3

PATIENT INFORMATION INPUT FORM

Introduction

Patient Information Input Form is the basis of the **DAT** system. The PC operates both as a file server and a data analysis system, hence the first stage of operation is the creation of a data file for a patient. This requires the entry of information onto the screen when prompted (Figure 3.1). The overall relation between the menu systems are shown in Figure 3.2.

```
               PATIENT INFORMATION INPUT FORM

  Name     : JOHN CITIZEN
  Sex      : M
  Age      : 52
  ID       : 00000000
  Adress   : 111 Johnston Ave St Pauls NSW 2031

  Measurement:  Rad  Car  Fem  ECG  Bra  Axl  S.C.  D.P  A.A
  Distances  :    0   10    0         0    0    0     0    0

  Sp (mmHg)  :  0
  Dp (mmHg)  :  0
  Medication :  Nil
          :
  Notes      : Normal
  Operator ID:  0

F1-Help F2-SaveToFile PgDn-InputPulse Alt-D-Delete End-Report Esc-Quit
```

Figure 3.1. *Data entry form for input of patient data and visit information.*

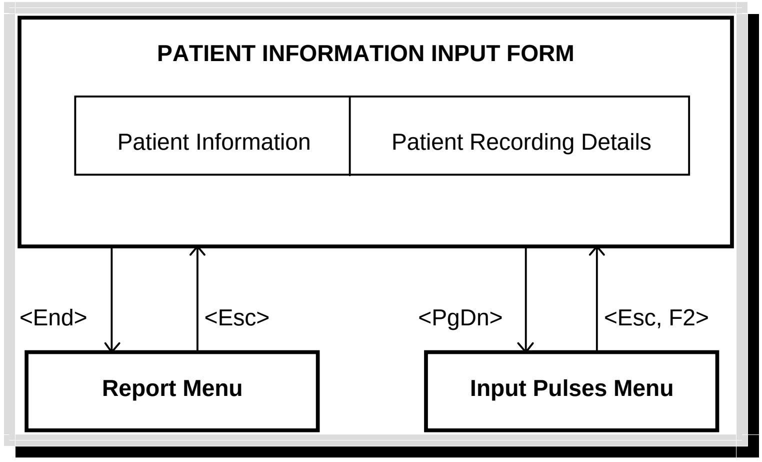


Figure 3.2 *Diagram showing the interplay of menu systems with respect to Patient Information Input Form.*

Information Fields and Their Usage

NAME

The name of the patient. Note that all the patients are indexed according to this entry. Therefore it is a good practice to use either a first name-surname combination or a surname-first name combination consistently in all the entries. Omit all punctuation during the key entries. If the patient information has already been recorded in the system, then by pressing the <**Return**> key after entering the patient's name, the remainder of the patient's identifying data will be displayed.

SEX

Either **M** for male or **F** for female.

AGE

To the closest birthday, enter the age in number of years.

ID

The hospital identification number for that patient or an arbitrary number given by the system user.

ADDRESS

The home address of the patient. Enter as Street Number/Street Name/Suburb/Postcode.

The following particulars for the current examination must be entered:

SITE, DISTANCES and ORDER

If required for calculation of pulse wave velocity (see page 34), the chosen site is nominated by pressing the <**Enter**> key when the cursor is superimposed over the nominated site which will then be highlighted. Distances should be from suprasternal notch to the measurement site in centimetres.

More than one peripheral site may be nominated for a given examination with the sequence of examination chosen previously. Alternatively, next examination site may be entered individually after each examination. Selection of a site may be cancelled by pressing the <**Enter**> key with the cursor overlying the site name. The operation is confirmed by the disappearance of highlighting over the site name.

SYSTOLIC and DIASTOLIC PRESSURES

Values relevant to the site of measurement as determined by a sphygmomanometer or read from the patient monitor. For radial artery tonometry brachial sphygmomanometric blood pressure values are entered. For carotid tonometry, reconstructed ascending aortic blood pressure values as determined from brachial or radial pressure waveforms are used. If the system is calibrated previously (see Chapter 4), then the system will calculate the systolic and diastolic blood pressure values from the internally calibrated input pulse waveform. To do this a "zero" value should be entered for systolic and diastolic pressures.

MEDICATION

Two lines are available for this entry, and entered data will appear on the report form.

CLINICAL NOTES

This information will not appear on the report, therefore it is only for reference.

OPERATOR ID

This value is for the identification of operators. A value between 1-99. The zero value is assigned for unidentified operators.

Keys and Functions

Editing Keys

The following keys permit the editing of data:

- <⇐> Moves cursor left
- <⇒> Moves cursor right
- <⇑> Moves cursor up

- <⇓> Moves cursor down
- <¬> Deletes the character on the left side of the cursor
- **<Del>** Deletes the character under the cursor
- **<Ins>** Toggles insert mode. If it is on, it allows characters to be inserted at the cursor point.
- **<Tab>** Moves 8 characters at a time
- **<Return>** Accepts an entry
- **<Enter>** Accepts an entry

Command Keys

<F1> **HELP** function key.

This key can be used at any data entry point when the user is unclear as to what needs to be entered.

<F2> **SAVE TO FILE** function key.

Following the entry and/or editing of patient data, this key must be pressed in order to save to a patient file in the computer disk. Otherwise any alteration or modifications will be permanently lost.

<PgDn> **INPUT PULSE** function key.

This key initiates recording and diagnosis procedure of the selected pulses. For more information of this option see Chapter 4.

<End> **REPORT** function key.

This key permits the commencement of the reporting procedure of the patient. The report of the patient will begin from the most recent recording. Upon return from this option the information about the last viewed recording is available for viewing and/or editing. For more information of this option see Chapter 5.

<Alt-D> **DELETE** function key.

This key is for deleting a patient information including the recordings from the file system. It is useful when erroneous patient information has been typed and saved.

<Alt-E> **EDIT** function key.

This key is for editing a patient name including the recordings from the file system. It is useful when erroneous patient information has been typed and saved.

<Esc> **QUIT** function key.

This key is used to permit the operator to quit the program and return to the operating system.

CHAPTER 4

INPUT OF THE PULSE

Acquisition of the Pulse

The **DAT** program will automatically proceed to the Input Pulses Menu after the patient information and pulse selection(s) have been completed in the Patient Information Input Form by pressing the <**PgDn**> key. The first selected pulse site can now be used as input. Connect the cable carrying the selected signal to the channel 0 (zero) of the A/D Board. The screen will display the acquired waveforms in real time with a pressure scale in mmHg displayed on the vertical axis. The ordinate legend will be the current selected pulse site

Calibration of the Pressure Pulses

Before applying the tonometer, establish zero and 100 mmHg calibration through internal electrical settings of the tonometer box by pressing <**Alt-S**> key. First, it will query the 0 mmHg pressure signal and then the 100 mmHg pressure signal. The system will average the corresponding values of presure for 1/2 seconds to eliminate noise. By using these two values the gain and offset of the the system will be calculated and later will be used to scale the pressure waveforms.

Sound Generation

In case of difficulty in observing the screen during signal registration, a sound generator is PC's speaker to frequency modulate the acquired signal. Thus it provides a feedback to the operator on the amplitude and frequency of the pressure wave. This generator is toggled by <**Alt-D**> key. The sound simulates those generated from a doppler flow meter, with low-to-high pitch sound corresponding to pressure signal going from a low to a higher signal level.

Triggering

The pulse train is triggered by itself during signal analysis. If, however, an ECG waveform has also been selected in the Patient Information Input Form as a triggering source for signal analysis, the first derivative of the ECG waveform (or other signal such as another pressure wave) will also be displayed on the upper half of the screen. The data recording system expects ECG signal in the second channel following the pressure signal of the A/D converter (by default channel 1). By pressing <**+/-**> keys a user can adjust the amplitude of the ECG signal, eliminating overriding signals on the screen.

Selecting the Pulse

The position and pressure on the tonometer probe should be adjusted until the waveforms are reproducible from beat to beat and of good contour and amplitude (usually in the range of the Patient Information Input Form systolic and diastolic pressure values), and with a stable baseline. The principle of applanation tonometry requires that the front wall of the artery be flattaned by the instrument.

Feature Extraction

When approximately two and a half screens (10 seconds) of continuous waves fulfilling the above criteria have been obtained, the operator should press the <**F2**> key. The screen is then frozen and the **DAT** system analyses 8 seconds of pressure data by excluding the very last 1/2 screen (2 seconds) of data. This exclusion is neccessary to eliminate possible artefacts caused by delay of a single operator in using the keyboard. A chart illustrating the whole process is given in Figure 4.1.

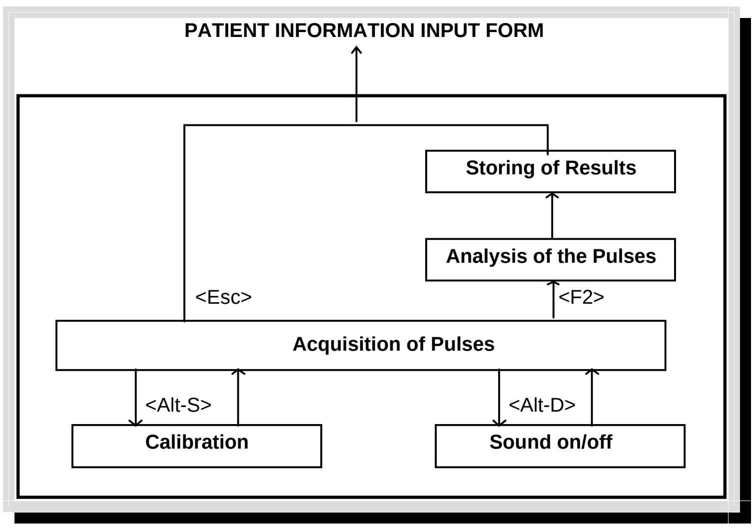


Figure 4.1 *Connections between the command structures of Input Pulses Menu.*

Keys and Functions

Command Keys

<F1> **HELP** function key.

This key can be used at any data entry point when the user is unclear as to what needs to be entered.

<F2> **DIAGNOSE** function key.

This key is used when satisfactory waveform has been acquired for at least 10 seconds. The screen freezes and the **DAT** system analyses approximately the last 8 seconds of data.

<Alt-S> **CALIBRATE** function key.

This key is used when the calibration of pulses is required. After setting external pressure source connected to the transducer to 0 mmHg, press <**Esc**> key when instructed. Then, set the external pressure to 100 mmHg and press <**Esc**> key.

<Alt-D> **SOUND** function key.

This key is used to toggle sound generation ON or OFF.

<+/ -> **TRIGGER** function key.

These keys are used in conjunction with the ECG trigger source when this is being used. If your ECG signal is too high and therefore obstructing the viewing of the pressure signal you can alter ECG waveform amplitude by pressing these keys.

<Esc> **QUIT** function key.

This key is used to permit the operator to quit the Input Pulses Menu and return patient information input form without analysing the data.

CHAPTER 5

REPORT GENERATION

Introduction

The report(s) of a patient may be viewed at any time by pressing the <**End**> key from the patient information form.

Viewing of Patient Recordings

Upon entry to the report system it will display the current or most recent recording. The operator can select the previous, next, first and last recordings of the same patient by pressing <**PgUp**>, <**PgDn**>, <**Home**> or <**End**> keys respectively.

Generating Reports of Recorded Pulses

The report is composed of two components which can be displayed alternately by <**Space Bar**> toggle. The default component is a graphic display of the acquired peripheral arterial and calculated central aortic waveforms (Figure 5.1, Top), which are 8 seconds in length. Averaged representations of these waveforms are displayed on the lower half of the screen. The important features of the averaged pulses are also marked to facilitate feature extraction. Blood pressure values as well as timings are also displayed. The second component is a written report including the patient data information, calculated indices of the peripheral artery and calculated central aortic waveform (Figure 5.1, Bottom).

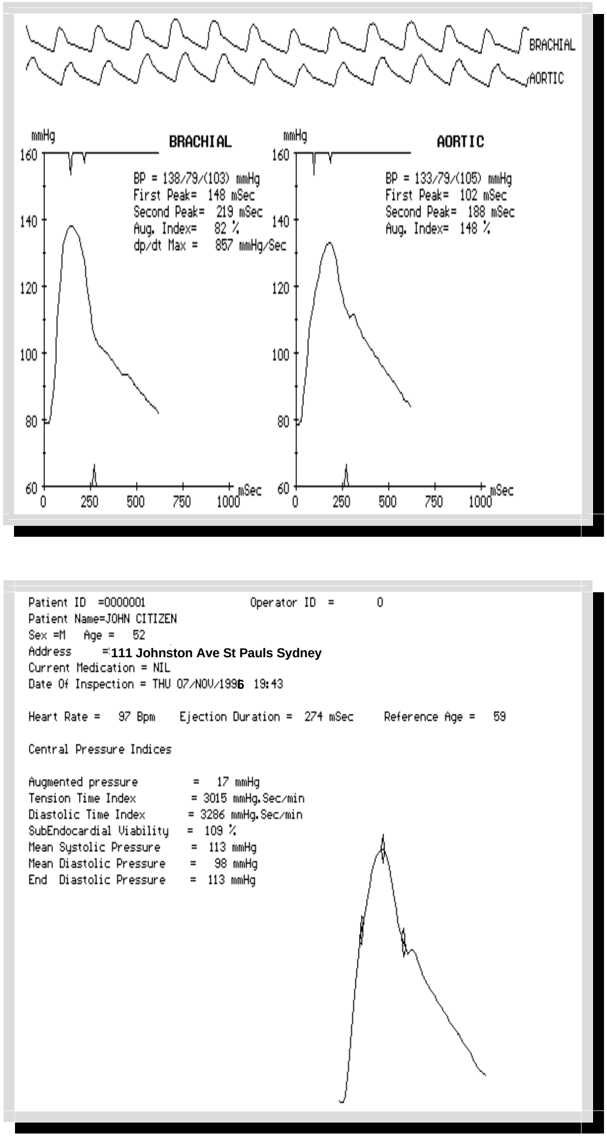


Figure 5.1 *A sample of graphic report displayed on the screen. Top panel shows the recorded (top) and the averaged (bottom) peripheral and calculated central pulses. Alternate screen obtained by pressing the space bar (Bottom panel) shows the patient information together with calculated central indices. The inset displays the averaged central pressure waveform with corresponding features of the first peak, second peak and incisura. .*

Printing a Hard Copy

If a printed report is needed, a hard copy of the selected pulse from the monitor (Figure 5.2) can be obtained by simply pressing <**F2**> key. Ensure that the printer, its connections and the graph paper are all in place correctly before pressing <**F2**> key.

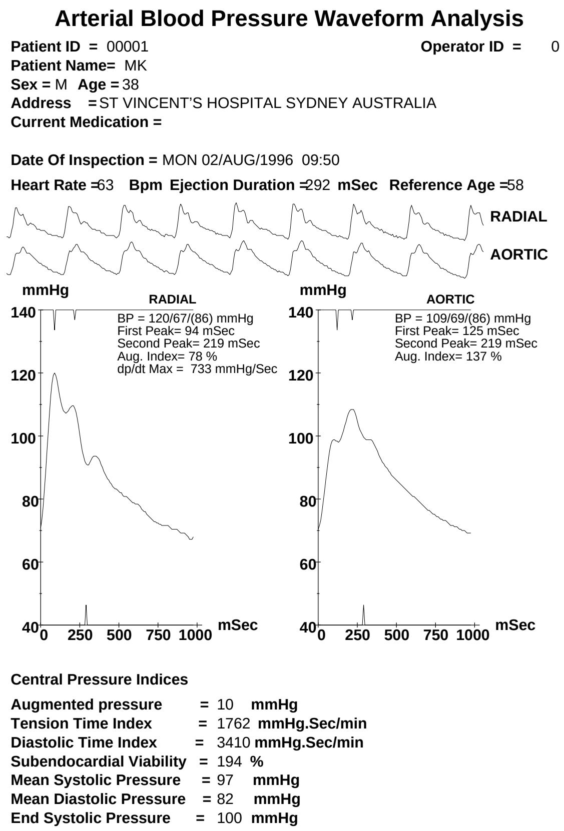


Figure 5.2 *A sample of hard copy of the report.*

Explanation of Report

The recorded wave set (above) and synthesised ascending aorticwave set (below) recorded over an 8 seconds period are each ensemble averaged into a single recorded (left) and synthesised (right) wave. Flags are placed along the waves where the first systolic and diastolic wave peaks have been identified. The time to these wave peaks from the foot of the wave are given in milliseconds alone the wave, together with the augmentation index (height of wave foot to second peak divided by height from foot to first peak). Maximum dp/dt is given for the recorded, but not with the synthesised wave. For the recorded brachial and radial wave, systolic and diastolic blood pressure is that determined by sphygmomanometer abd mean is determined from integration of the wave. The aortic pressures are determined from the peak, nadir and integrated mean of the synthesised wave,

The flag at the bootom of the ensemble averaged wave represents the timing of the incisura, The same timing is applied to the synthesised wave.

Central pressure wave indices at the bottom of the report are:

Augmented Pressure

Pressure difference between the first peak (or shoulder) of the synthesised wave and the second peak. This is usually positive but may be negative in young adults, with vasodilator therapy, with tachicardia or eith hypotension. If either the first or second peak cannot be identified a (??) indicator will appear.

Systolic (Tension) Pressure Time Index

This is the inegral of pressure x time throughout systole and expressed over a minute (see Sarnoff Sj et al (1958) Am J Physiol 192:148-156)

Diastolic Pressure Time index

This is the inegral of pressure x time throughout diastole and expressed over a minute (see Buckberg et al (1972). Circ Res 20: 67-81)

Subendocardial Viability Ratio

Ratio of diastolic pressure time index to systolic pressure time index. A value of 100 % is often associated with impaired subendocardial blood flow. (see Buckberg et al (1972). J Thor Card Surg 164:669-685)

Mean Systolic Pressure

Average presssure between the wave foot and identified incisura (see O'Rourke (1967). Cardiovasc Res 1:313-316)

Mean Diastolic Pressure

Average presssure between the incisura and beginning of the next wave (see O'Rourke (1967). Cardiovasc Res 1:313-316)

Patient identification data appears at the top if the report as entered by the operator. Immediately below this is printout

Heart rate in beats/min

Ejection duration (time from wave foot to incisura) in milliseconds

Reference age. This is derived from comparing augmentation of the recorded wave with augmentation determined a group of 1005 normal subjects (see Kelly et al (1989). Circuation 80:1652-1659)

Keys and Functions

Command Keys

<F1> **HELP** function key.

This key can be used at any time when the user is unclear as to what needs to be done.

<F2> **HARD COPY** function key.

The F2 key can be used if a printed copy of the currently viewed report is required.

<PgUp> **PREVIOUS** function key.

This key is used to display previous reports. The reports are filed in order of entry with the most recent report being the first to be displayed.

<PgDn> **NEXT** function key.

The <**PgDn**> key is depressed if the user wishes to view more recent reports.

<Home>FIRST function key.

This key is reserved for selecting the first recording of the patient.

<End> **LAST** function key.

This key is reserved for selecting the last recording of the patient.

<Alt-D> **DELETE** function key.

Delete the displayed record.

<Spacebar>TOGGLE function key.

It is used to toggle between the graphic and text components of the recording.

<Esc> **QUIT** function key.

This key is used to permit the operator to quit the Report Menu and return to the Patient Information Input Form. The Patient Information Input Form will now display the information related to this recording.

CHAPTER 6

ADVANCED TOPICS

Configuration File

DAT learns about the environment under which it is running by examining the **DAT.CFG** file. This file is an ASCII file which contains information about the A/D Board, Printer setup as well as the paths to the data files. In order to inform the DAT for the path to the directory of DAT.CFG, you can either type **SET DATPATH=** PATH in command line or use **EDLIN** or a line editor to edit AUTOEXEC.BAT file.

first line

This line in **DAT.CFG** file specifies the program to acquire the data. It can be a batch program to acquire and display the data. By default this line is set to "DT280X 0 2", indicating a program with Data Translation boards using channel zero as the pressure source with internal gain of 2. For internal programmable gain see operations manual of the Data Translation board. It is hoped in the future different drivers which would supplement the acquisition module. Currently **DAT** comes with a driver interface to A/D boards manufactured by Data Translation Corp.

second line

This line is the gain of the entire analogue circuit at the front end of the A/D board. This value is useful if one uses different analogue equipments to capture the pressure and ECG waveforms.

third line

This line is the offset of the analogue circuit at the front end of the A/D board. This value is useful if one uses different analogue equipments to capture the pressure and ECG waveforms.

fourth line

This line is the printer device driver program for generating reports. It can therefore be a batch program. **DAT** currently supports three device drivers for printer support. For dot matrix printers it is "DOTMTRX <option> " where option is 9 or 24 for 9 pin or 24 pin printers. For PostScript printers it is "PSTSCRPT" and for PCL printers it is "HPPCL". The output of these drivers can be directed to Standard Output devices to be filtered or piped. For example the following batch program could be called by this option to put a header to the report

COPY HEADER.EPS LPT1:

PSTSCRPT >LPT1:

where HEADER.EPS is an encapsulated PostScript file containing the header. Similarly the output can be directed to a file which could then be inserted to a word processing program.

fifth line

This line is the database path where the PATIENT data file used by the **DAT** system resides. This feature is useful if one wishes to separate data for different tasks. For example data from the intensive care unit might reside in directory ICU while the clinician's office data might reside in OFFICE sub directory. The master database which combines the both might be in sub directory MASTERDB. This kind of separation of databases increases the security and good maintenance of data.

sixth line

This line is the database path where the RECORDS data file used by the **DAT** system resides. This feature is useful if one wishes to separate data for different tasks. For example data from the intensive care unit might reside in directory ICU while the clinician's office data might reside in OFFICE sub directory. The master database which combines the both might be in sub directory MASTERDB. This kind of separation of databases increases the security and good maintenance of data.

seventh line

This line is the database path where the index files of PATIENT data file used by the **DAT** system resides as in line five

eighth line

This line is the database path where the index files RECORDS data file used by the **DAT** system resides as in line six.

Command Line Interface

The command Line Interface is used to handle information from specified database sources. The command line options are invoked by the syntax:

DAT <option> <Standard Input >Standard Output

Here **<option>** stands for either **A**, **C**, **D** or **N:**

<A>is for *appending* data from other databases. This option is useful if one keeps a master database for patients and recordings and a different database in different media and wishes to append the latter to the former. DAT checks the existence of the same records in the master database and if it fails to find one, it appends the recording onto the master database.

*Note: The master database directory should be given in **DAT.CFG** file.*

<C>is for *re-diagnosing* of the existing database with changed parameters. This is especially useful for future updating of the **DAT** program on the existing databases. It assumes the index key to the recordings be given through standard input device. Normally this key is the output of option **<N>** (see below).

<D>is for *deleting* certain records from the database. It assumes the index key to the recordings be given through standard input device. Normally this key is the output of option **<N>** (see below).

<I>is for *installing* **DAT** to a directory. This feature finds use when a first time or repeated installations are needed.

<N>is for *dumping* names in the database. This feature is not only useful in dumping the index key to the contents of databases but also useful for other command line options to be used as an input. **DAT** responds to this command by asking the name of patients to be dumped. For example in response to the command

DAT N <Enter>

where DAT responds with

Name= **DAV**

allows one to dump the names and recordings of the patients who has names starting with DAV. The output of the **DAT** becomes

P ~ Record Number ~ Patient Name

where P is a letter indicating an entry to the Patient database, ~ is a separator, Record Number is the number associated with the database and

R ~ Record Number ~ Patient Name ~ Date of Inspection

where R is a letter indicating an entry to the Recordings database, ~ is a separator, Record number is the number associated with the database.

<O>This option tells **DAT** to *output* the averaged recorded peripheral pulse. The data are written to files which are created by the DAT. The files are named as *Filename.Extension* where *Filename* is the name of recording site and *Extension* is the number starting from "000" and incrementing by one up to "999". These numbers correspond to the output obtained by **<N>** option.

<P> Is for unattended *printing*. **DAT** repeatedly calls line four of DAT.CFG program to output to the print device. The input will be the index key to the recordings which is the output obtained by **<N>** option.

<R>This option tells **DAT** to *report* the extracted information about the patients and recordings in ASCII format. The input will be the index key to the recordings which is the output obtained by **<N>** option. The output is separated with commas and in the order of:

1. Name
2. Sex
3. Age
4. Operator ID
5. Medication
6. Date of Inspection
7. Heart Rate
8. Foot of the wave[Raw]
9. Foot of the wave[Central]
10. First peak time [Raw]
11. Pressure At First Peak[Raw]
12. First peak time [Central]
13. Pressure At First Peak[Central]
14. Second Peak Time [Raw]
15. Second Peak Time [Central]
16. Systolic Pressure [Raw]
17. Systolic Pressure [Central]
18. Diastolic Pressure [Raw]
19. Diastolic Pressure [Central]
20. Mean Pressure [Raw]
21. Mean Pressure [Central]
22. Ejection Duration [Raw]
23. Ejection Duration [Central]
24. Augmentation Index [Raw]
25. Augmentation Index [Central]
26. Maximum dp/dt [Raw]
27. Maximum dp/dt [Central]
28. Tension Time Index
29. Diastolic Time Index
30. Subendocardial Viability Ratio
31. Mean Systolic Pressure
32. Mean Diastolic Pressure

33. End Systolic Pressure
34. Augmented Pressure
35. Recording Site
36. Estimated Reference Age

<U>is for *upgrading* the database to a recent version. This option is used if the version of DAT is later than the existing one. The DAT then asks the name of the database to be upgraded. It the creates two databases with extension "NEW" which contains the upgraded versions of the old versions. One can then either edit the DAT.CFG file denoted by DATPATH statement to rename these files as new database files of rename the extension "NEW" as the old databases. It is advised that this command should be issued in a new directory to eliminate chances of confusion. Since this option does not check the presence of the old file, it is the users responsibility to confirm the presence of old database.

<X>is for *extracting* data from current databases. This option is useful if one keeps a master database for patients and recordings and wishes to extract patient information and recording information from it to another database. It assumes the index key to the recordings be given through standard input device. Normally this key is the output of option **<N>** (see above).

CHAPTER 7

TECHNICAL CONCEPTS

Overview

The basis of the **DAT** system is the acquisition of pulses from a peripheral site (radial, carotid, femoral, brachial, axillary, subclavian and dorsalis pedis artery) or from ascending aorta by means of a pressure registration device (tonometry, volume clamping or invasive catheters) and analysing the waves due to existing knowledge about the pulse. Pressure wave propagation parameters such as reflection coefficients and pulse wave velocities are calculated to quantify the effects of different drugs or manoeuvres on the arterial vasculature. It also contains a database management system based on pressure recordings which can be coupled with other diagnostic and therapeutic tools. To achieve all these goals, the software includes routines for signal acquisition, signal conditioning, feature extraction, parameter calculation, database maintenance and report generation (Figure 7.1).

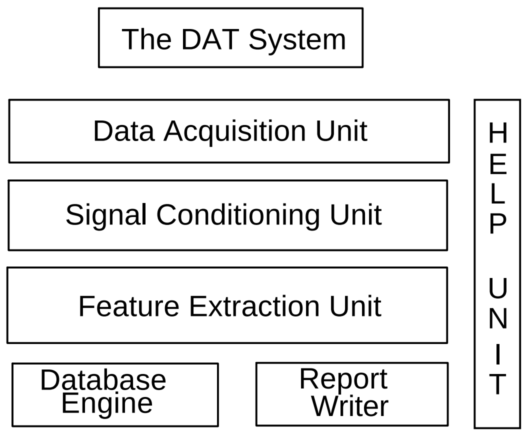


Figure 7.1 *The components of the* ***DAT*** *system showing the hierarchy and interplay of separate units.*

The peripheral pulse is acquired at a rate of 128 hz using an A/D converter. The sampling rate is fixed at this frequency since it not only facilitates operation of Fast Fourier transforms (FFT) using techniques described by Blackman-Tuckey algorithms but also it is well above the bandwidth of pressure signals. This choice of frequency is low enough to reduce overhead in data storage and analysis while high enough from aliasing errors. By doing so, it is guaranteed that the same harmonic will always lie in the 1 hz window. The clock pulses necessary to generate this sample interval is generated by the computers (IBM-PC) timer chip, (Intel 8255) (although a clock on an A/D board would also suffice) generating an interrupt to be serviced. The use of the system clock allows utilisation low cost A/D boards which do not posses internal timer or interrupt generating capabilities. Since the timer interrupts were used to synchronise the data acquisition steps, they were not available to the operating system. Before data acquisition module takes control, the vector pointer at address $0000:0020 Hex for timer interrupt ($08 Hex) handler of BIOS was changed to the interrupt servicing routine of the **DAT** system (Figure 7.2). This technique modified the priority scheme of the timer interrupts. Since same timer interrupts are also used by DOS in time keeping activities, BIOS and DOS routines are activated at regular intervals to update the system clock.

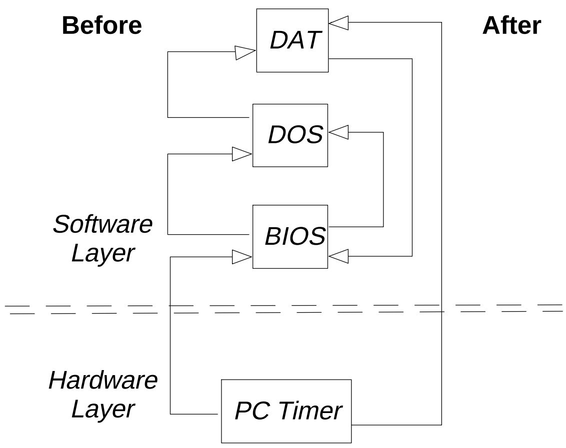


Figure 7.2 *The modification of original interrupt vector Table for timer interrupts. Arrows indicate the order of execution of code after each received interrupt. Under normal circumstances the priority is to the BIOS, DOS and then the user program. Alteration of the vector sequence also alters the existing priority.*

At each interrupt, the CPU reads data from the A/D ports representing the pressure (P_S) and if present, the trigger (T_S), Figure 7.3. The channel numbers for these signals are assumed to be sequential, the channel for P_S being the first, and given in the configuration information. The P_S is then copied to a circular buffer of 10 second length. Thus to fill the buffer once, 1280 samples are necessary. If the trigger signal is not present, then P_S is also copied to a buffer of equal type and size for trigger information, otherwise T_S will be copied into it. On-line calculation of aortic pressure waveform is also performed during the acquisition step of the pulse. The P_S is directed to a convolution buffer, where it is convolved with the window representing the inverse transfer function (see below) to yield an ascending aortic pulse (C_S). The C_S is stored into the same size circular buffer. If D/A channels are available, an identical copy of C_S and P_S are dumped out from these ports. The P_S is then displayed on the screen in a rotating drum sequence. If present the derivative of the trigger signal (T_S) is also displayed. The same process is repeated continuously until terminated by the user.

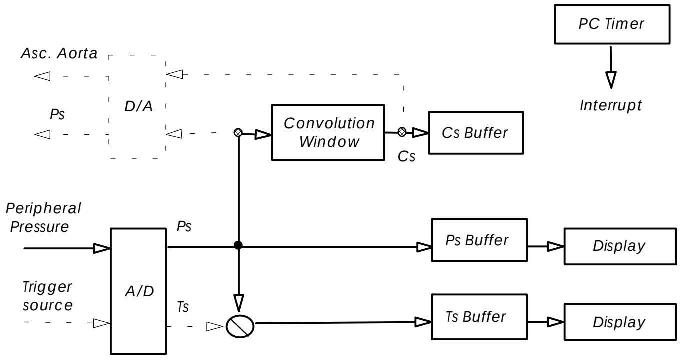


Figure 7.3 *Block diagram of the data acquisition section of the DAT system. Peripheral pressure waveform and trigger source is fed into to the respective buffers where they are kept and displayed. Peripheral pressure is convolved with the respective filter and stored as central pressure waveform. Due to presence of D/A converters the pressure signals (raw and convolved) are dumped out. Entire events are synchronised with PC timer interrupts. Dotted lines indicate optional paths.*

For recording sites between the ascending aorta and either carotid, radial, femoral, brachial, axillary, subclavian or dorsalis pedis a transfer function is determined either by direct calculation from *in vivo* data or from the model. From this, a convolution window is calculated for each transfer function. To obtain a cut off frequency at 16 Hz, the resultant window is then stored in a look-up Table of 33 samples long for each patient. Normally, this window function yields an estimate of the central pressure value for each sample after (W+1)/2 convolutions, (W is the window length). This operation introduces a linear delay of sampling period*(W+1)/2.

Signal Conditioning

Upon the user's request data from buffers (C_S, $P_S$and T_C) are transferred to the database records, excluding the last 2 seconds to allow for data interruption which may occur during the initiation of the request. The PC timer is then stopped and updated by the system parameters while real-time clock registers are also updated. The contents of all buffers are smoothed using 7-point moving average filters to limit the bandwidth of the signals to 20 Hz. The data string in buffer T_C is then differentiated and further smoothed using first forward differentials and 3-point moving averages to find the triggering points and to eliminate the noise amplified during differentiation. Maximal and minimal thresholds are defined as the 60% of the maximum and minimum derivatives in the entire buffer content. This value for threshold is determined empirically after trying for several pulses. The positions of the onset of pulses are then determined by comparing them against the maximum threshold. The segments within these maximal and minimal thresholds are marked. The corresponding data from P_S and C_S are averaged to yield averaged recordings of peripheral and synthesised waveforms. The averaged P_S is then calibrated using given pressure values. The numerical values for P_S and C_S are then used to estimate overall gain and offset of the system. The calibration values obtained this way are subsequently used to calibrate the synthesised aortic pulse.

Feature Extraction

DAT extracts five time relative points on the waveform from which parameters relating to the heart and arterial system are determined, (Figure 7.4).

Features of the Arterial Pulse

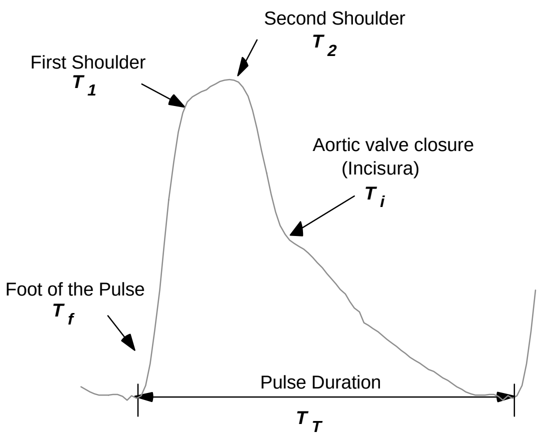


Figure 7.4 *The basic features of the arterial pulse. After the foot of the pulse indicating the onset of ejection determined from the trigger source, the pressure wave rises to an initial peak where it forms a shoulder. It then proceeds to a second shoulder which often constitutes the peak pressure in the elderly. The former point is related to timing of peak flow while the second shoulder to reflected waves. The end of ejection is associated with closure of the aortic valve which is often seen as a distinct incisura on the aortic pressure pulse.*

They form the positions describing the foot, first shoulder, second shoulder, incisura and the duration of the pulse. Since these features are geometric and could be described as inflection points along a curve, they can be identified using differentials of different orders. Of all the points on the pressure waveform, particular importance is given to the systolic onset (foot of the pulse), maximum of the first derivative (upstroke of the pulse) and systolic point (maximum of the pressure pulse). All other points can then be expressed in relation to these points, thus providing consistency in comparisons.

Calculated Values

From averaged peripheral and synthesised central pulses the following values are calculated:

Ejection Duration

$$ED(Secs) = T_i - T_f$$

Heart Rate

$$HR(Beats/\min) = 60/T_T$$

Pressure at Diastole

$$P_d(mmHg) = P[T_f]$$

Pressure at Systole

$$P_s(mmHg) = P[T_p]$$

Mean Arterial Pressure

$$MAP\ (mmHg\ ) = \frac{\sum_{i=1}^{T_T} P_i}{T_T}$$

Pressure at First Shoulder

$$P_1(mmHg) = P[T_1]$$

Pressure at Second Shoulder

$$P_2(mmHg) = P[T_2]$$

Augmented Pressure

$$AP(mmHg) = P[T_2] - P[T_1]$$

Mean Diastolic Pressure

$$MDP(mmHg) = \frac{\sum_{i=T_i}^{T_T} P_i}{(T_T - T_i)}$$

Mean Systolic Pressure

$$MSP(mmHg) = \frac{\sum_{i=T_f}^{T_i} P_i}{(T_i - T_f)}$$

Augmentation Index

$$AI(\%) = 100 \times \frac{P_2 - P_d}{P_1 - Pd}$$

Tension Time Index

$$TTI(mmHg.Beats/\min) = HR \times MSP \times (T_i - T_f)$$

Diastolic Time Index

$$DTI(mmHg.Beats/\min) = HR \times MDP \times (T_T - T_i)$$

Subendocardial Viability Ratio

$$SVI(\%) = 100 \times \frac{DTI}{TTI}$$

Reflection Transit Time

$$RT(Sec) = T_2 - T_1$$

Maximum Rate of Rise

$$Max\, dP/dt\, (mmHg/Sec) = Max\left(\frac{dP}{dt}\right)$$

Reference Age

$$\text{RA(Years)} = 0.642 \times (AI - 100) + 33.81$$

Reference Age is the age corresponding to the augmentation index as derived from ageing studies. "P[]" indicates the element of the pressure waveform array.

Database Engine

Since it is assumed that there will be further enquires regarding the recordings in the future based on epidemiological and short term research, a database engine is installed as part of the software. The data preserved are the raw and averaged data for each peripheral and calculated central aortic waveforms as well as indices and values derived from them. A separate database is linked to the recording's database by the name of the patient and the time of visit (Table 7.1). This second database keeps the information regarding the patient particulars such as age, sex and anatomical and diagnostic data (Table 7.2). Type definitions for each record are given in Tables 7.3 and 7.4.

FIELD	TYPE
Patient Name	Small String
Date of visit	Small String
Medication	Array[1..2] OF Small String
Notes	Small String
Operator Id	Word
Trigger Present	Boolean
Diagnosed	Boolean
Gain of System	Real
Offset of System	Real
Trigger Series	Array[1..128] of Integer
Recorded Pulses	Array[Raw..Convolved] of Pulse Buffer
Heart Rate	Real
Augmented Pressure	Real
Reference Age	Real
Tension Time Index	Real
Diastolic Time Index	Real
Subendocardial Viability Ratio	Real
Mean Systolic Pressure	Real
Mean Diastolic Pressure	Real
End Systolic Pressure	Real

Table 7.1 *The template for record of database file "RECORDS". This file is indexed with Patient Name field and Date of visit and linked to PATIENTS database. For explanation of defined types see Tables 7.3 and 7.4.*

IELD	TYPE
Patient Name	Text String
Patient ID	String[8]
Patient Age	Integer
Sex	String[2]
Address	Small String
Distances	Array [Radial.. Aortic] of real
Convolutions	Convolution Types

Table 7.2 *The template for record of database file "PATIENTS". This file is indexed with Patient Name field and related to RECORDS database. For explanation of defined types see Tables 7.3 and 7.4.*

To facilitate retrieval of archived information, the transaction time is kept to a minimum by indexing both the "PATIENTS" and "RECORDS" databases on their key fields (Table 7.1) using AVL-trees. As opposed to B-trees which becomes unbalanced when sequential insertions are made, AVL trees balance the B-tree at each insertion and deletion so that there will be $\log_2 N$ levels present in a B-tree at all times. This ensures that a maximum of $\log_2 N$ searches would be sufficient to access a particular record (N is the maximum number of elements in the tree). Using this algorithm, the software is able to locate a record from a list of 65536 recordings in at most 16 attempts. Provisions are also made to ensure integrity and distribution of the database across several platforms by obeying strict rules imposed by the system in accessing the database using indexes.

FIELD	TYPE
Pulse Name	Pulse Types
Tonometer Input Series	Pulse Stream
Averaged Pulse	Pulse
Length of Averaged Pulse	Integer
Systolic Pressure	Real
Diastolic Pressure	Real
Mean Pressure	Real
Time to Foot Of Wave	Real
Ejection Duration	Real
Max dp/dt:	Real
Systolic Onset	Real
Time to Incisura	Real
Reserved	Real
Time to First Shoulder	Real
Time to Second Shoulder	Real
Reverse Shoulder Index	Real

Table 7.3 *The type defined for any pulse. It contains information about the original series of pulse, averaged pulse and the derived indices. This buffer is duplicated for both raw and convolved signals and corresponds to PS and CS buffers in Figure 7.3.*

New Type	Definition
Small String	String[40]
Pulse	Array[0..255] of Real
Pulse stream	Array[0..1023] of Integer
Convolution Window	Array [-16..16] of Real
Pulse Types	Radial, Carotid, Femoral, Brachial, Axilla, Subclavian, Dorsalis Pedis, Aortic
Convolution Types	Array[Radial..Aortic] of Convolution Window
Signal Types	Trigger, Raw, Convolved

Table 7.4 *The type definitions based on ordinal definitions supplied by Pascal language used in record definitions.*

CHAPTER 8

HOW TO ?

Import Existing Tape Data to DAT

DAT does not differentiate between a real time signal and an off-line signal. Therefore it is possible to record signals from magnetic tapes as real time signals. Simply plug in the appropriate pressure and trigger signal to the data acquisition board, type in the particular details of the patient and proceed as usual. This feature is quite useful to archive the existing analog tapes in digital form using database features of the **DAT** system.

Conduct Different Studies Simultaneously

If you want to conduct studies involving different procedures and/or different sets of subjects you can install the **DAT** system in different directories. For example if you have a study to explore the effects of ACE inhibitors and NITRATES, install the **DAT** into sub directories called

- C:\ACE and
- C:\NITRATES

During performing the ACE experiment you can issue command

- SET DATPATH=C:\ACE

in DOS prompt and work in ACE environment while issuing

- SET DATPATH=C:\NITRATES

takes you to NITRATE environment.

Combine Different Databases

When you have two or more **DAT** databases such as the one given in the previous example and you want to append them to a master database you can use the **DAT** command line interface to perform this task.

For example, assume that you have a master database in drive D: and sub directory MASTERDB the commands that need to be issued are:

1. SET DATPATH=D:\MASTERDB

2. DAT A

DAT responds with:

Append Patients from=

Type:

- C:\ACE\PATIENTS.DAT

and

Append Records from=

Type:

- C:\ACE\RECORDS.DAT

DAT will append data from ACE study to the MASTERDB. Nitrates database can be appended similarly

Perform Statistical Analysis of the Data

Although the results of the reports can be typed into a statistical analysis program, it is more convenient to import the data to the same program as ASCII input.

For example assume that you want to analyse the data of patient(s) with initials S. The steps to perform this is

1. Select the appropriate directory using SET DATPATH= command

2. Type DAT N >NAMES

DAT responds with

Name=

3. Type A*

The names and recording times of patient names are now dumped into file named NAMES. Note: If you want to dump the entire names type just **<Enter>** or **<Return>**

4. Type DAT R <NAMES >RESULTS

The results of these recordings will be in file RESULTS which could be imported into any statistical package using ASCII import filters. The contents of dumped fields are explained in Chapter 6.

Print Unattended

Although you can print the reports while viewing them it is also possible and probably much easier to print them later. This can be done in two different ways:

- During interactive recording

1. Use a text editor to edit DAT.CFG file to change printer port in line 4 from >LPT1 to >>REPORTS

2. Run DAT as usual and print reports as usual. However, results of the reports will not be printed immediately but appended to a file REPORTS

3. Exit DAT

4. Type COPY REPORTS LPT1. LPT1 is the default printer port

5. Revert back to the default port by noting the default port in line 4 as in step 1

- During command line session

1. Consider you obtained a file called NAMES following the previous example. It is possible to print these recordings unattended.

2. Type DAT P <NAMES

DAT will print the recordings in NAMES file (ie the lines that starts with R~) to the device and port given in line four in DAT.CFG file. Please make sure that the printer has not run out of paper since no checking of availability of paper is made during printing.

Use Reports in Word Processors

Word processors using PostScript printers allow one to embed EPS (Encapsulated PostScript) files into documents. The graph given in Figure 5.2 is an example of such process. To perform this:

1. Use a text editor to edit DAT.CFG file. Change line 4 to PSTSCRIPT >REPORT

2. Type DAT

3. View the record to be embedded

4. Press <**F2**> to save it

5. Quit from DAT

6. Run your word processor and embed REPORT file into your document.

Record Waveforms Without Actually Seeing Them

Sometimes it may be hard to view the pressure pulses either due to inappropriate levels of pressure pulses or due to remoteness of the computer screen. The use of sound under these circumstances can help a trained operator since the generated sound is frequency modulated in conjunction with pressure pulse amplitude. Simply press <Alt-D> to turn the sound on and off.

Measure Pulse wave Velocity

In order to measure the pulse wave velocity you should select a triggering source which occurs simultaneously with the cardiac events. The best is either the carotid pulse or the lead II of an ECG. It can be selected by selecting the ECG button on the patient information input form. The pressure waves are then averaged by using the maximum rate of rise of these signals. By analysing the averaged pressure waveforms a foot is determined using the zero crossing point of the first derivative of the pressure waveforms. If this procedure is repeated at two anatomical sites to measure the pulse wave velocity of the segment in between two foot values are obtained. Subtracting the distances and the time to foot values and dividing them yields an estimate of pulse wave velocity.

For example for the pulse wave velocity in the arm:

- measure the carotid pulse with ECG triggering. Note the distance to substernal notch, l_c, and record the systolic onset time , t_c
- measure the radial pulse with ECG triggering. Note the distance to substernal notch, l_r, and record the systolic onset time , t_r.
- pulse wave velocity in the arm becomes:
- $$pwv(arm) = \frac{l_r - l_c}{t_r - t_c}$$

CHAPTER 9

WHAT TO DO IF ?

Cannot Run DAT Program

Database is corrupt

Delete all files ending with NDX and re-run DAT.

DATHELP.MSG is Missing

Path to DATHELP.MSG is invalid

Edit DAT.CFG to include the path

Cannot Register the Pulse. The System Crashes

A/D converter is not installed properly

Install the A/D converter at Address 2EC (hexadecimal).

Not enough memory

Increase memory or remove memory consuming drivers and/or terminate and stay resident programs

The clock speed of the PC is higher than 12 MHz

Reduce the clock speed of the PC

Cannot See Any Data on the Screen

Gain and offset have not been set properly

Use <Alt-S> to recelebrate the pulse in acquisition menu

Channel number does not match the analogue input

Edit line 1 of DAT.CFG

The System Crashes, no Feature is Extracted or Results are Wrong

Unexpected termination of the registration of pulses

Repeat the pulse acquisition procedure with less interruption in the last 10 seconds before pressing <F2> for diagnosis.

The PC system is too slow

increase the clock speed or add a math co-processor

Cannot Find a Recording Registered Previously

System date and time settings are wrong

Use Date and TIME Commands in DOS command line to set the date and time properly.

The path to DAT.CFG file is not correct

Use SET command to set a path to DAT.CFG file