INTERFACE OF A COMMERCIAL ELECTROCARDIOGRAM

SYSTEM TO HELP

by

Ween-Ping Tarng

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of a thesis submitted by

Ween-Ping Tarng

This thesis has been read by each member of the following supervisory committee and by majority vote has been found to be satisfactory.

Chair:

Stan M. Huf

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_____
Homer R. Warner
Chair/Dean

Approved for the Graduate Council

_____
B. Gale Dick
Dean of The Graduate School

ABSTRACT

The Electrocardiogram (ECG) Department at the Latter-Day-Saints Hospital has used a computerized ECG system for more than 15 years. In this automated system, all the ECG data were analyzed by a set of Health Evaluation Logic Processing (HELP) frames and the resulting interpretations were stored in the patient data base. In 1987, the Department replaced this system with the Marquette Universal System for Electrocardiography (MUSE). As a stand alone system, MUSE stores all its ECG interpretations in its own data base. Since the HELP system serves as the information center for the Hospital, it is necessary to establish an interface between the HELP and the MUSE systems so that the MUSE ECG interpretations can be stored in HELP and become available to the clinical personnel.

To integrate the MUSE system to HELP, one first faces the challenge of terminology difference between these two systems. According to the degree of compatibility among the terms used, there exist three categories of the MUSE interpretations. Different strategies were used in defining the Pointer to TeXT (PTXT) codes for these three categories of MUSE interpretations. In the process of constituting the PTXT representations for the MUSE system, care was taken to avoid duplicating existing codes in the HELP data dictionary.

The second issue in interfacing the MUSE system to HELP lies in understanding the MUSE statements. A MUSE statement may contain

different interpretations. Therefore, if a MUSE statement is to be stored in the HELP system, the interpretations constituting this statement must be understood so that their corresponding PTXT codes can be stored. In order to do this, a parsing algorithm was designed to detect different interpretations used in a statement and store their PTXT representations to HELP.

After the implementation of the interface software, it was found that the software was constantly ready to capture the MUSE data into the HELP system. In addition, all the MUSE ECG statements, after being processed by the parsing algorithm, had been transferred to semantically corresponding interpretations. These interpretations were stored as patient records and were available to the reviewing physicians throughout LDS Hospital.

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CHAPTER 1

BACKGROUND

Computers have long been used in the medical field for processing and interpreting physiological signals. One of the earliest applications in clinical settings has been the computer-analyzed electrocardiogram (ECG). In the late 1950s, efforts were devoted to the development of a computerized electrocardiogram system at several locations in the United States. It was formally applied to clinical settings in the early 1970s. [1] Computerization of the ECG has since achieved considerable success in both clinical research and commercial products. It is becoming a part of everyday clinical practice throughout the world.

The latest developments in computerized ECG show a trend toward networking where the automated ECG system is part of a centralized computer-based, hospitalwide information system. In such a system the computer is responsible for organizing, centralizing, and extracting clinical information. [2] The information, after being organizationally managed, is available to medical personnel or clinical applications for further utilization.

To effectively manage the information collected, a hospital information system is usually equipped with a comprehensive data base. The data base serves as a reservoir in which all the clinically significant data are collected for centralized management. The ECG data provide valuable information on

the abnormal activities of the heart cells, and should be instantly stored into the patient data base whenever it is generated. If a hospital relies on a stand alone computerized system to collect patient ECG data, this system should be integrated as part of the network of the hospital information system so that all the computer-generated ECG interpretations can be fed into the comprehensive data base.

The ECG Department at the Latter-Day Saints Hospital in Salt Lake City, Utah has computerized its ECG system for more than 15 years. In this system, all the data generated by the Department were analyzed by the frames of HELP (Health Evaluation Logic Processing), an information system for the hospital. The HELP frames compared the relevant data with built-in criteria and suggested appropriate interpretations. These interpretations were stored into HELP's data base as part of the patient's record. This automated ECG system was closely related to the HELP system and operated in the Hospital until 1987 when the ECG Department replaced it with a new system called MUSE (Marquette Universal System for Electrocardiography).

The MUSE system, designed by the Marquette Electronics Inc., is capable of collecting and analyzing the ECG data. As a result, the MUSE system has replaced the HELP frames for generating ECG interpretations. However, since MUSE is an independent system, all of its interpretations are stored in its own data base. Since the HELP system is the central information station for the whole hospital, there is a need to transfer the MUSE ECG interpretations to the HELP patient data base. The need to integrate the MUSE system into HELP sets the goals of this research project.

1.1 History of the Automated ECG system at the
Latter-Day Saints Hospital

The ECG Department at the Latter-Day Saints Hospital, a 550-bed medical care center serving the needs of the intermountain west, in Salt Lake City, Utah has computerized its ECG system since 1969. Figure 1 shows an overall diagram of the old system. When the automated system was first installed, a patient's electrocardiographic signals were collected using a Marquette 3 channel ECG recorder and the data were then transmitted into the central Control Data 3300 Computer System through a telephone line. The analysis was performed using the orthogonal XYZ Frank lead system. The signals from the modified Frank X, Y, Z leads were amplified and sampled simultaneously and then fed into an A/D converter and multiplexor. After the signals were interfaced to the computer, they were passed to the wave-form recognition and measurement modules. Parameters that were easy to measure and clinically significant were calculated. These selected parameters were then input into a logic system developed to classify the waveforms and formulate interpretations using a series of Boolean statements. [3, 4] After analysis was performed, the outcome interpretations were generated by the computer and passed to the physician for overread. The physician was provided with a list of all ECG interpretations and their associated nomenclature codes. If an interpretation was not deemed appropriate, the physician could cross out that interpretation and replace it with the code desired. The confirmed report was then entered by a technician who typed in all the codes, and subsequently, all of the interpretations were stored in the file of that patient.

It is important to know that the automated ECG system at the ECG

4
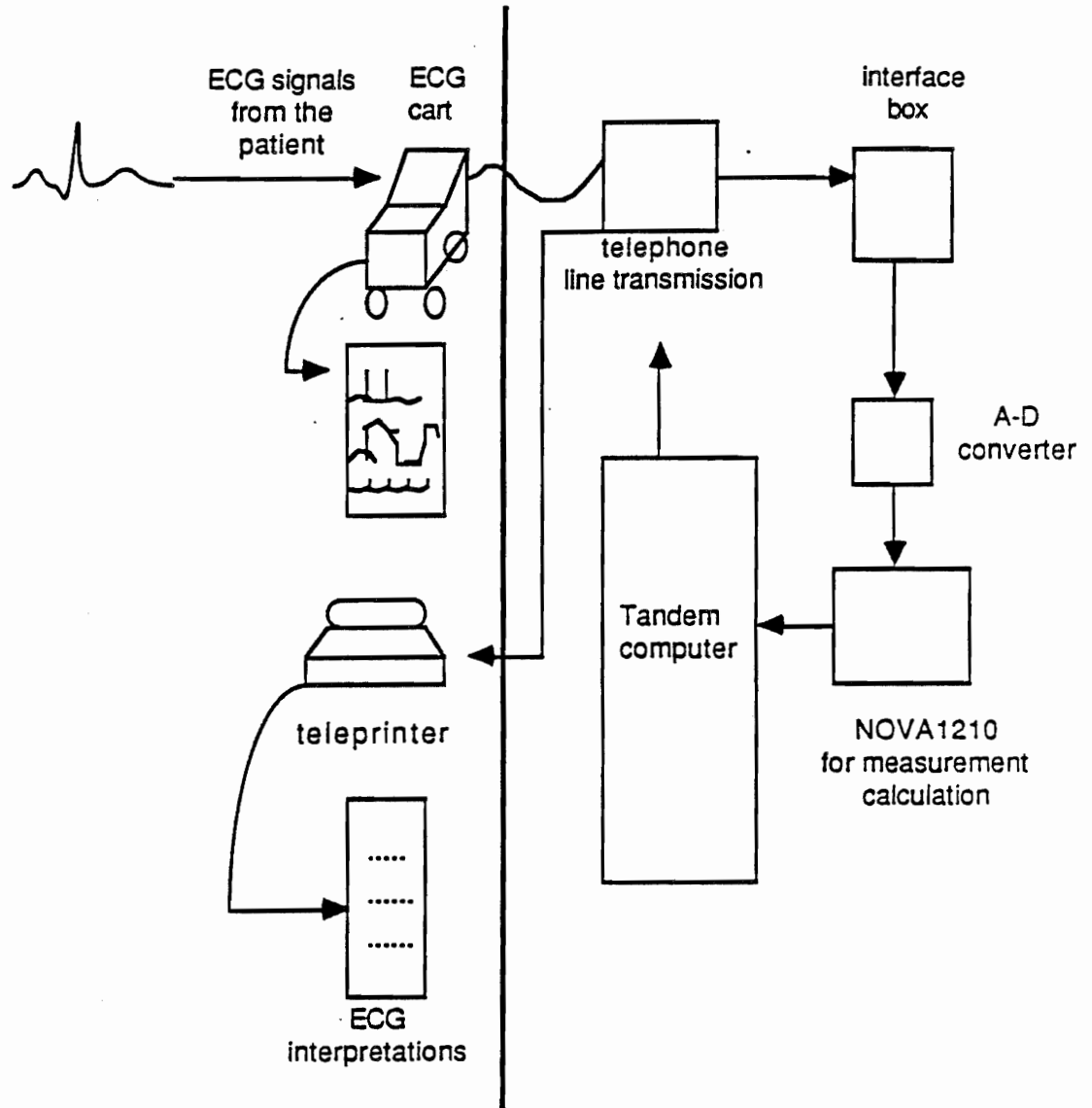
Figure 1. A block diagram of the previous automated ECG system at the LDS Hospital.

department is an inseparable portion of a comprehensive computer information system that serves the hospital as a whole. This system, designed to meet the administrative, clinical and research needs of the LDS Hospital, is called the HELP system. From its beginning stage in the early 1960s, HELP's designers set forth to explore the use of the computer in clinical diagnosis. [5] After years of continued development, HELP has become a clinical information system capable of acquiring clinical data and maintaining its ever-expanding data base. In addition to data storage, the HELP system is characterized by its medical decision making capability. The system supports the building of a knowledge base in which experts' knowledge and extracted data base statistics accumulate to help in the construction of decision logic. With the built-in logic processing ability, the system can examine the collected patient data and arrive at some clinically important alerts or suggestions.

From the discussion above, it is understood that data collection as well as decision making are two essential aspects of the HELP system. The HELP system manages its data by using a data dictionary system called PTXT (Pointer To teXT). By using this program, a user can define the code for a data item as well as the English text for future reporting. As for decision making, HELP allows users to construct a modular unit called a frame. Inside the frame, the user specifies the criteria needed for a specific diagnosis. By searching through the patient data base using the PTXT for desired data items and executing a frame to compare the obtained data items against a stipulated criteria within a frame, HELP informs its user of the most likely interpretation.

The early computerized ECG system made full use of all the capabilities

of HELP. The modules used in interpreting the ECG data were typical decision making HELP frames. As the incoming signals were processed, waveforms and measurements would be recognized and calculated. These data were automatically fed into the ECG diagnosis frames. The frames analyzed the measurements, generated the appropriate interpretation according to its Boolean criteria, and stored the resultant interpretation into the patient file. The interpretation stored, of course, was in the form of a PTXT code so that the computer could interpret and report this piece of data to human users.

1.2 The Marquette Universal System for Electrocardiography (MUSE)

In 1987, the ECG department decided to update its ECG system by replacing its older ECG machines with the Marquette 12SL system. The new system acquires an ECG record consisting of all 12 classical ECG leads obtained simultaneously over a 10 second period and each individual complex can be analyzed in all leads. As shown in Figure 2, the ECG data acquired from a patient are analyzed with a bedside cardiograph (MAC 12). The interpretation summary and waveforms can be either transmitted directly into the Marquette Universal System for Electrocardiography (MUSE) over a telephone line or they can be recorded on a magnetic tape or diskette and fed back to the system for batch processing. As soon as the MUSE central system acquires a patient's ECG data, it creates a file under the patient identification number and permanently stores all the pertinent information into that file. The MUSE system then prints out the preliminary interpretations to be overread by a physician. Most of the time, the physician agrees with
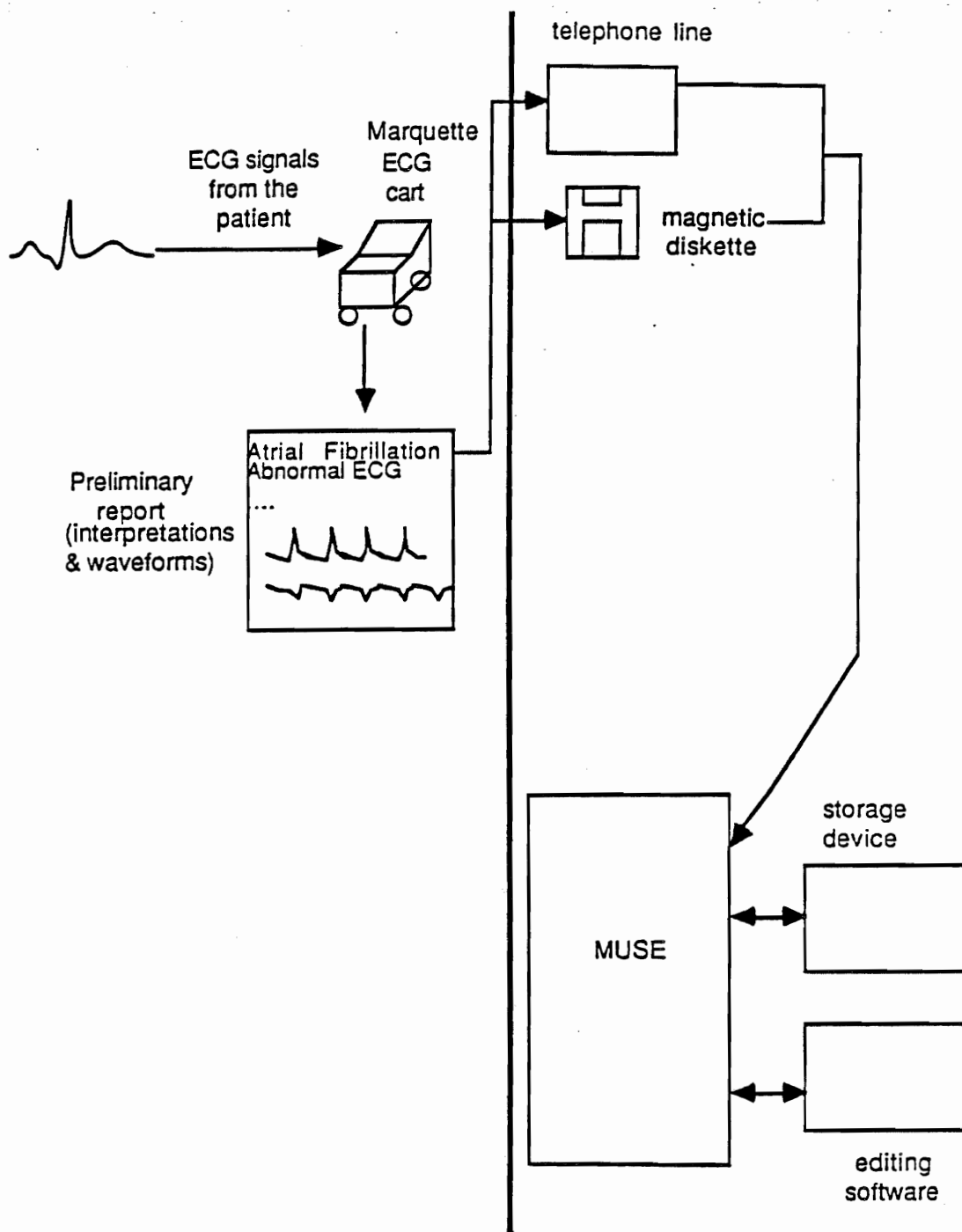
Figure 2. A block diagram of the MUSE system at the LDS Hospital.

the computer, however, he or she may still want to make some modifications or additions. The physician can draw a line on an unwanted statement, replacing that statement by writing a MUSE mnemonic abbreviation for the message desired. To add more statements, he or she simply writes down the abbreviation for the added message on the preliminary report. [6, 7] Although freetext messages are also allowed, it is preferred that the physician use terms listed in the MUSE library. The MUSE library currently contains approximately 300 statements, allows addition of new statements and change to the statement nomenclature. For example, in the MUSE library AB, which stands for ABnormal ECG, can be replaced by a numeric code "001". All the computer-generated codes, after physician's overread, would be given to the technician who uses an interactive program at a terminal to make the changes marked by the physician. The MUSE system automatically expands the abbreviation of each interpretation to the full statement and stores each interpretation together with the waveforms from 12 leads and patient identification information on magnetic discs. All the stored data can be easily retrieved to any peripheral device by using a retrieval program; furthermore, upon the reading physician's request, the MUSE system can also retrieve any previous tracings with the waveforms and interpretations for a particular patient.

1.3 Problems of Interfacing the MUSE System to HELP

The new ECG system performs the ECG interpreting work satisfactorily and brings more automation to ease the amount of effort needed to get the data stored. However, as mentioned above, the HELP system at the LDS Hospital is the central data base as well as the decision making station.

Therefore, it is necessary that once ECG measurements and interpretations are generated by the MUSE system, they enter into HELP immediately for prompt utilization and centralized management. If it is accomplished, not only does the ECG department have the direct access to all the data of their patients through the MUSE system, but at the same time the data are on line and available to other medical personnel who wish to review a patient's most current cardiological condition through the terminals. In other words, the MUSE system should be integrated into HELP and serve as part of the hospital information network.

To integrate the MUSE and the HELP system, one first faces the problem of terminology differences between these two systems for ECG interpretations. Disagreement in the ECG interpretations arising from differences in measurement technique, terminology, or criteria has long been a major problem for computerized ECG systems. [8] The problem also exists between HELP's former ECG coding system and the MUSE interpretations. When the HELP frames for ECG data analysis and interpretation were first created, the cardiologists in the hospital had decided on a set of codes for ECG interpretations and used this set of terms for more than 10 years. Altogether there were 200 messages plus 70 modifiers. Each of these messages, as described above, had a corresponding PTXT code in the HELP data dictionary system. On the other hand, the MUSE library provides 242 statements and 63 general modifiers. With the discrepancy between the terminology used, many Marquette messages lack corresponding matches in the HELP coding list. However, most of the differences are semantic rather than substantive. Some of the MUSE messages do have semantically corresponding PTXT codes, though the terms used by the two systems have

a slightly different look. An example of this case is the interpretation of left ventricular hypertrophy determined by voltage criteria. For the MUSE system, the interpretation appears as "VOLTAGE CRITERIA FOR LEFT VENTRICULAR HYPERTROPHY" while in the HELP system it appears as "LVH - VOLTAGE CRITERIA ONLY". Unfortunately, in these two systems there are not many matching terms. Most of the time a MUSE message is semantically an equivalent of the combination of several HELP expressions; and it is not rare to find messages in either of the systems that simply do not resemble any message in the other system. It may seem natural to discard the old coding system and replace it with a new set of PTXT codes that are completely representative of the MUSE interpretations. However, if the old codes are forsaken, the HELP system would have difficulty interpreting the ECG data collected before 1987. Based on this, it seems justified to leave the old ECG PTXT codes intact and create another set of codes for the MUSE system. This solution, however, would create the problem of redundancy since there are some messages in these two systems that match. The first challenge then is to construct an ECG coding system capable of representing both the old and the new diagnostic messages, and at the same time, avoid duplicating terms in the data dictionary that contain the same information.

Another problem encountered in interfacing the MUSE system to HELP is to understand the statement structure of a MUSE message and correctly interpret the message so that it can be appropriately substituted by the HELP PTXT. Unlike the old coding scheme, the statements of MUSE do not use the principle of one interpretation per statement. For the old system, one computer statement corresponded to only one interpretation listed in the coding scheme. Modifiers could be added to the statement according to the

degree of probability of the statement criteria. If the old system generated an interpretation message, say FIRST DEGREE AV BLOCK, and if it is validated by a physician, a technician would enter it into the system by typing in its code 09.1. This message could also be modified to express the degree of possibility: FIRST DEGREE AV BLOCK POSSIBLE. In this case, the codes used include 09.1 and PO. A matching table inside the computer system would link the code 09.1 and PO to their PTXT representations of 3 3 64 20 0 0 0 0 for "first degree AV block" and 3 131 64 0 0 0 13 for modifier "possible". These PTXT codes would be stored in the patient's file. The MUSE statements bear a different complexion. For example, one line of Marquette statement may look like SINUS BRADYCARDIA FIRST DEGREE AV BLOCK WITH OCCASIONAL VENTRICULAR PREMATURE COMPLEXES which in fact, contains 3 different diagnostic messages "SINUS BRADYCARDIA", "FIRST DEGREE AV BLOCK", and "VENTRICULAR PREMATURE COMPLEXES" and one modifier "WITH OCCASIONAL". Besides, the MUSE system, when transferring its Marquette interpretation to any other computer system, would have the data transferred as actual ASCII characters instead of an abbreviation or a code for this interpretation. Obviously, building a matching table inside HELP to link every interpretation with its PTXT codes, as for the old system, does not seem practical any more. Therefore, in order to interface the Marquette system with HELP, one needs to develop a strategy that can distinguish different message segments in each Marquette statement and can actually "understand" the meaning of each character string so as to assign appropriate PTXT codes for each of them.

The problems mentioned above define the domain for this research, namely, designing a set of PTXT codes for representing the interpretation of

the new MUSE system as well as the old HELP ECG interpretation and development of software which will understand the MUSE statements and represent them with semantically corresponding PTXT codes. To solve the first problem, one has to take into consideration two aspects: The first one is to save the PTXT capability of interpreting the old ECG data; the second one is to avoid creating redundant MUSE codes in PTXT. Chapter II addresses these two questions and proposes a solution. As to the issue of developing a program to handle MUSE statements, Chapter III discusses the development of a technique which involves using a "word dictionary" to parse a complicated MUSE message into several clinically self-contained interpretations to be stored into patient's records. The overall performance of the interface software will be discussed in Chapter IV and some of the messages resulted from the parsing process will also be reported.

CHAPTER 2

MARQUETTE INTERPRETATIONS AND THEIR
PTXT REPRESENTATIONS

Every computerized electrocardiographic system should be able to
analyze physiologic variations from QRS complex to QRS complex,
recognize and measure recorded waveforms, and deal with variations in the
quality of the recorded ECG. Based on the input waveforms, the Marquette
as well as the HELP analysis programs formulate their own interpretive
statements. However, owing to the differences in the terminology used, the
statements used in these two systems appear to be quite distinct. Upon a
closer examination of the differences existing between these two
nomenclature systems, three categories can be identified by the degree of
compatibility among the terms used. The first category consists of
interpretations which exist in both coding systems. The second category
contains terms that resemble each other to certain degree. The last group
covers the interpretations that are totally unique to each coding system.

2.1 Marquette Interpretations That can be Paired
With the Existing PTXT Codes

Among 303 Marquette interpretations, approximately 100 of them can be
semantically paired in the HELP interpretation group. Interpretation pairs
belonging to this category do not necessarily have exactly the same term but

do contain the same meaning. Examples include the statements of "BIVENTRICULAR HYPERTROPHY " in Marquette and its pair "COMBINED RIGHT AND LEFT VENTRICULAR HYPERTROPHY" in HELP; "WITH 2:1 A-V CONDUCTION" in Marquette, and "WITH 2:1 CONDUCTION RATIO" in HELP.

Most of the time, the modifier statements such as "POSSIBLE" and "PRESENT" of these two systems can be matched. But it is not unusual to find a Marquette modifier that also belongs to this category by having a corresponding HELP interpretation which, instead of being a modifier in nature, is a regular and self-contained statement. "WITH JUNCTIONAL ESCAPE COMPLEXES" is, for example, a Marquette modifier which is used only to modify other rhythmic interpretations. But with HELP, it is itself a complete interpretation for describing one of the junctional mechanisms. This kind of Marquette modifier is also classified as having semantic equivalents in HELP. Appendix A lists the Marquette and the HELP messages which are deemed to have the same connotation.

Some of the Marquette interpretations also belong to this category although they do not have a single corresponding match in the data dictionary. Those interpretations, however, can have their messages fully expressed by a combination of several PTXT codes. Interpretations of this kind can be best exemplified by a Marquette interpretation like "T WAVE INVERSION NO LONGER EVIDENT IN". Though this interpretation does not have an exact HELP match, it can be expressed by combing a HELP code and a modifier: "T WAVE INVERSION" and "NO LONGER PRESENT". Marquette messages like this are not numerous in quantity and they are listed in Appendix B.

2.2 Marquette Interpretations That can be Partially
Expressed by the Existing PTXT Codes

Among other Marquette interpretations, some denote messages
resembling the HELP expressions in some degree. It is not unusual to find
that a Marquette interpretation can only be partially substituted by some
HELP statements. Appendix C contains Marquette interpretations that
resemble HELP codes only in some degree. A Marquette interpretation like
"UNUSUAL P AXIS AND SHORT PR, PROBABLE JUNCTIONAL
TACHYCARDIA" can find some corresponding HELP statements such as
"JUNCTIONAL TACHYCARDIA" and modifier "PROBABLE" for the second
part of the sentence, but since HELP lacks an expression like "UNUSUAL P
AXIS AND SHORT PR", this Marquette interpretation can not be fully
explained by the current HELP statements.

2.3 Unique Marquette Interpretations

Finally, some of the Marquette messages are totally absent in the HELP
data dictionary. A message like "SERIAL COMPARISON NOT PERFORMED,
ALL PREVIOUS TRACINGS ARE OF POOR DATA QUALITY" or "LEFT
ATRIAL BRADYCARDIA" in Marquette is completely unique to the MUSE
system, and those interpretations are displayed in Appendix D.

For these three categories of the Marquette interpretations, the third
category outnumbers the other two. The number of interpretations for these
categories are listed below:

Category	Number of interpretations
1. Interpretations with exact matches in HELP	
a. one exact match	101

b. a combination of PTXT codes   15

2. Interpretations partially expressed by PTXT codes   26

3. Unique Marquette interpretations   161

As mentioned in the previous chapter, if the Marquette system is to be integrated into HELP, a coding system must be designed both to adapt the new interpretations and to avoid duplicate terms. Before further discussing how this may be accomplished, the structure of the HELP data dictionary needs to be first understood.

2.4 Data Dictionary Of the HELP System -- PTXT

All data items in HELP are represented using PTXT. The previous HELP ECG automated system also had its interpretations stored in the data base in the format of a PTXT representation. To interface the MUSE system to HELP, it is necessary to translate each Marquette statement into data items representable with the HELP dictionary. Therefore before incorporating the Marquette coding system into HELP, one has to understand the basic structure of PTXT in order to design appropriate PTXT records for all Marquette interpretations.

Functioning as the data dictionary in the HELP system, PTXT links the data item's English text definition and its value to a code understood and manageable by the computer system. In the HELP system, all the clinical data are stored on disk in their PTXT coded format so that they can be translated back to common English terminology for reviewing. Each PTXT code, which contains 8 bytes to form a unique primary key functioning as a pointer to the text record in the TEXTFILE, is created from the position of the defined term in a hierarchical structure for medical terminology. This

hierarchical structure consists of several levels: Data Class, Field Code, Noun, Adjective, Adverb, and Modifier. Data Class is used to define a subspecialty area of medicine. For example, ECG measurements and interpretations comprise one data class which is data class three. Under data class, different data types determine the various string structures. The system supports type zero, type one, type three, and type seven. Type zero strings are defined relations and each data string has a fixed length. For a type zero string, every data item is defined according to its specific location in the string. The measurement matrix generated from the old ECG system was stored as type zero and each word in the string represents a value of a particular measurement. Type seven strings have a structure which is a combination of type zero and type one. Type one and type three strings are two particularly important string types in PTXT: A type one string is the most versatile and frequently used structure in PTXT while type three data strings are used to represent HELP decisions. These two types will be illustrated in more detail.

Type one data have a structure that best exemplifies the hierarchical scheme of the PTXT codes. For type one data, each string is first classified under a data class. After data class, a level indicator specifies how many levels this string has, that is, would it stretch downwards to include a noun, an adjective, or an adverb. When type one data are to be stored as a record in the patient file, the system precedes each layer of element with a certain delimiter. For example, a delimiter is used to indicate that a noun or a modifier will follow; after this information another delimiter is used to define the next coming element. This data format, which allows flexible construction of data strings of various depths and offers versatile usage of data structure,

has become one of the most essential data types in PTXT.

Type three strings are used to store the results of HELP decision logic. A type three data string usually contains data class, field code (or block number), and a frame number of the HELP frame from which the decision is made.

2.5 The PTXT ECG Interpretations

In the HELP system, frames written for a specific medical division are often grouped together and form a unit of frame block. It has been estimated that more than 2000 frames are currently operating in HELP and they are primarily involved with ECG interpretations, blood gas interpretations, pharmacy alerts, X-ray reading suggestions, and clinical laboratory alerts. All the frames involved in a specific clinical area are grouped in a block. Whenever relevant data enter the system, this block of frames can be run against that piece of data for desired clinical suggestions or alerts. For ECG interpretations, 252 frames are grouped as a block whose number is 64.

Before the installation of MUSE, the ECG interpretations were generated by running the ECG frames in block 64. The frame interpretations were stored as type three strings. The code of a type three string consists of data class, type, block number, and frame number and each ECG frame within block 64 is assigned a number ranging from 1 to 252. If the frames run with the ECG measurements, and the criteria within a frame are met, then the PTXT code 3 3 64 frame-number, which stands for a specified message, is stored in the patient file. If the diagnosis has a probability of certainty associated with it, block modifiers such as "PROBABLY" can be appended to modify the string.

2.6 Integration of the Marquette Interpretations
Into HELP's Patient Data Base

As indicated in the first section of this chapter, there is some discrepancy between the Marquette interpretations and the old ECG codes. This problem can not be solved by simply creating a new set of PTXT codes for the Marquette system and replacing the PTXT codes of the old statements with the new PTXT codes. Once a PTXT for a data item no longer exists in the data dictionary, HELP simply fails to translate that data item back to the text understood by human users. Therefore, if the old PTXT codes are removed from the system, there would be no way to interpret the tracing of ECGs done before 1987. However, if the new and old sets are both kept in the system, the problem of redundant terms would arise.

The strategy for integrating the Marquette interpretations, owing to the nature of the discrepancy, is threefold. For the semantically matching pairs of Marquette and the old codes, the PTXT codes simply remain intact. Whenever such a Marquette interpretation appears, one just stores the corresponding old PTXT into patient records. For the Marquette interpretation which is a combination of several old terms as shown in Appendix B, the PTXT for the constituent HELP terms would all be packed into one unit and get stored as one data string. However, some Marquette messages can not be or can only partially be explained by the old ECG codes. There is not much choice for these kinds of statements other than creating new PTXT codes for them. Now the decision focuses on the structure of the new PTXT codes. Most of the PTXT in HELP is arranged such that clinical diagnosis and alerting messages are usually the result of frame logic, and therefore, belong to type three data. Though the Marquette messages are generated and transferred from the MUSE system and are not

products of HELP decision making procedure, they are in nature interpretations derived from logic inferring operations. In order to follow the classification guidelines of PTXT string types, the required new PTXT codes for Marquette interpretations were created as type three strings which are also classified under data class three and block 64. Altogether there are 119 PTXT codes of this kind that needed to be created. These new PTXT codes are also independent interpretations; therefore it seems natural to treat them like the other regular ECG PTXT codes. However, there is some limitation in the hierarchy of the PTXT which forces one to consider carefully the arrangement of these new PTXT codes.

The hierarchical structure of PTXT has a restriction on the number of data elements in each level. For each layer in the hierarchy, only 256 data items can exist in juxtaposition. As mentioned above, the hierarchical structure of type three data includes data class, field code, and frame number. Since 252 HELP ECG diagnosis frames already exist, if the 119 new codes are to have the same structure, the total number of the frames under block 64 would exceed 256. Fortunately, under each HELP frame, there is a special level of modifier called frame text modifier that can be used to modify the message issued by a frame. An example here can show how the frame modifier is used to help in interpreting sinus mechanisms. Block 64, frame 19 contains four frame modifiers: 1. Normal Sinus Mechanism, 2. Sinus Tachycardia, 3. Sinus Bradycardia, 4. Ectopic Atrial Rhythm. The frame logic first examines ventricular regularity index, number of pads, and PR interval. If they all fulfill certain criteria, then it proceeds to examine the value of the heart rate to determine which frame message to use. If, for example, heart rate is greater than 60, then frame modifier 3, or sinus bradycardia, is the resultant message

for sinus mechanism. Since each layer of hierarchy can have 256 data items, 256 frame text modifiers can be used in one frame. As one can see, a frame text modifier can, under the dominant clinical subject of the master frame, be itself a complete message. Therefore, to find a place for the Marquette interpretations in the PTXT hierarchy, one can create a HELP frame designated for displaying the new Marquette ECG interpretation and array the 119 statements as text modifiers for this frame. It was found that frame 101 in block 64 was not set up for any particular usage, so it is now the Marquette frame which contains 119 frame text modifiers. The PTXT for a frame text modifier appears to be 3 131 64 0 frame-number 232 0 sector-text-modifier-number.

In addition to the 119 codes added to frame 101, many new modifier PTXT codes were created. Some of the new modifiers were generated for the Marquette modifying statements like "LARGE", "FREQUENT", or "WITH RATE DECREASE". Other new PTXT modifiers were created out of the repetitively appearing terms for anatomic information and myocardial injury or ischemia manifestation. Terms of this kind include "ANTEROLATERAL", "INFEROLATERAL", "SUBENDOCARDIAL", "ENJOY PATTERN", and "ISCHEMIA" . They are used extensively in the interpretations describing ST and T wave abnormalities. All these anatomic and injury pattern descriptions are used interchangeably to form different combinations of ST and T interpretations. Therefore it is reasonable to create modifier codes for them and simply append these modifiers to the leading ST or T wave statements. With these modifiers at hand, it is not necessary to create different regular codes for the ST and T statements which contain duplicated anatomic and myocardial injury information.

All the type three PTXT codes mentioned above, whether a simple frame text or text modifier, are all dummy structures if they are used to represent Marquette statements since HELP is no longer involved in ECG interpretation. The ECG type three PTXT codes stored in the data base now are from Marquette analysis. They are not outcomes from executing HELP frames but rather the results of Marquette interpretations transferred from MUSE to HELP.

A Marquette statement can contain several interpretations extracted from its interpretation library, and if such a statement is to be stored in HELP, the messages it connotes must be made distinct so that PTXT codes corresponding to the different message segments can all be stored. The problem of correctly parsing a Marquette statement into corresponding PTXT codes therefore became the essential part of this research and is discussed in detail in the following chapter.

CHAPTER 3

UNDERSTANDING A MARQUETTE STATEMENT

3.1 Data Communication Between MUSE and Tandem

The MUSE system has the versatility and capability of recruiting many

facilities and devices to establish its own network system. The central system

acts as the major station for data collection, analysis, and storage, but it also

allows the system manager to set up an information network by

communicating with other medical facilities according to their need to access

the central ECG files in the MUSE system. It is this capacity that makes

possible the communication between MUSE and the HELP system.

With a RS-232 cable, the MUSE system in the ECG department is directly

connected to the Tandem computer's port 231. The system manager of

MUSE set up the Tandem computer as one of its network sites and specified

the type of this site as CPU-to-CPU link. After setting up the Tandem

computer as a peripheral device of the MUSE, the manager selected the

formats of the data to be transmitted. Among the data formats provided by

MUSE, only the Marquette interpretations and the measurement matrix of a

confirmed ECG report are requested by the system manager to be sent to this

site. The incoming Marquette diagnostic messages will be available on line

for physician's review from the nurse stations, and the measurement matrix is

stored into HELP for other research purposes. Finally, the MUSE manager

specified the communication process is to be carried out in an automatic mode. That is, all the statements and measurement matrix of a particular ECG are automatically transmitted to the Tandem site of a baud rate at 4800 bps after the preliminary report of this ECG has been edited by a technician in the ECG department.

The MUSE system, which is composed of a PDP 11/73 computer and a secondary storage device, provides a CPU/CPU communication option which allows textual data generated on the MUSE system to be transmitted to a facility computer system. Through the MUSE communication option, all Marquette generated ECG reports can be transferred to the Tandem computer. The following sections will give an overview of the communication process.

The communication process of the MUSE system consists of a log-on phase, a data transmission period, and a log-off phase. [9] During the entire communication process, the MUSE system treats theTandem computer as a terminal, sends it data and waits to receive some control signals back. It should also be noted that for MUSE CPU-to-CPU type of communication, only ASCII data can be transmitted.

3.1.1 Log-on

The MUSE system provides a facility for users to define a log-on protocol. Under the site setup menu selection, a special utility called LOGON PROTOCOL allows the host system personnel to define the interactions between MUSE and host computer during the log-on phase. By using the LOGON PROTOCOL, a user can construct a file that contains a series of commands executable by the MUSE resident command interpreter. Once a

logon file is defined, the MUSE can log onto the host system using the specified protocol.

In order to minimize log-on failures due to complicated message exchanges, the MUSE-Tandem logon procedure is kept as simple as possible, and it includes only the following steps:

1) WT*90   (wait 90 seconds before log onto the host system)

2) TN*HELLO<CR   (send log-on message "HELLO" and expect no echo)

3) WT*5   (wait 5 seconds before data transmission starts)

4) TO*20   (set time-out period to be 20 seconds)

5) ST*<LF><LF><CR>   (specifies transmitted data format which includes two line feeds and a carriage return as terminators)

The reason for waiting 90 seconds before transmitting the log-on message to the Tandem is because sometimes a new communication process is requested right after a previous communication has finished. The 90 second delay period allows the Tandem to finish handling the last record of the previous transmission and come back in time to attend the next communication. The "HELLO" message is to alert the Tandem of the presence of a new communication process. Before data communication starts, a delay of 5 seconds is granted. The time period of 20 seconds is stipulated before a time-out message is issued. The ST command signifies the start of data transmission. The trailing three control characters are terminators for the line number, the data line, and the checksum during data transmission.

Another parameter needed to be set up for the log-on protocol is the delay between records. A record is defined as a single patient's ECG

interpretations; the delay between records is the time in seconds that MUSE will wait after completion of transmission of one record and before the next record is sent. In order to give the Tandem computer enough time to perform necessary analysis on the record just received, a 95 second delay is given for the multirecords transmission between these two systems.

3.1.2 Data Transmission

Data of an ECG are transmitted one line at a time, and each line is composed of a line number, a data line, and a checksum. A line number is a counter for the host system to check that the data line has not been missed. It contains at most three ASCII characters and continues up to 999. A data line contains clinical information to be analyzed by the host computer. A checksum is a decimal sum of the characters contained in the data line. Expressed also in ASCII, a checksum can have at most six characters. As specified in the logon protocol, both line number and data line will be terminated by a line-feed while the checksum is followed by a carriage return.

Various control messages are exchanged between the MUSE and the host system to perform handshaking during data transmission. The messages are ACK, NAK, ERR, EOR, IRM, and EOT. The positive acknowledge message ACK is sent by the host system to the MUSE after it verifies the line number, checks the data line by comparing the received checksum with its calculated checksum. The MUSE waits a certain period of time for the ACK message after the transmission of one data line. It declares a time-out error and attempts a retry if it fails to receive ACK after the time period specified in the logon protocol. NAK is issued by the host system to

MUSE if either the line number is out of order or the calculated checksum does not match the checksum received. After receiving six consecutive NAK or declaring six time-outs for the same line, the MUSE logs the error, sends the error message ERR to the host system, and terminates the connection. After a given time period, the MUSE will try to logon to the host system again and attempt to retransmit the entire record instead of just the line in error. The EOR, IRM and EOT are sent by the MUSE to indicate the end of record, inter-record period, and end of transmission. Once the EOT appears, the host system knows that the whole data set has been successfully transmitted and the MUSE is going to logoff the system after a given period of time.

3.1.3 Log-off

Like the log-on protocol, the log-off protocol can also be specified using the site setup menu selection and the same set of commands. The procedure used for MUSE-Tandem logoff phase is as follow:

1) WT*5

2) TN*LOGOFF<CR>

3) ST*<LF><LF><CR>

Once the Tandem computer sees the presence of the "LOGOFF" message, the data-receiving software knows the whole communication is completed, and it will loop back to the starting position and awaits a new logon initiation.

At the receiving site of the communication process, a program written in TAL (Tandem Application Language) is ready all the time in the Tandem computer for collecting and analyzing the MUSE messages. As the MUSE transmits one line at a time, the program checks the data line and checksum. If everything is correct it would write this line into a temporary file. Each write

statement in the program creates an entry or record in the file, and the sequence of all entries is determined by the order of their arrival. The structure of this file is entry-sequence. The content of such a file after a patient's data have been completely transmitted is shown in Figure 3. Now that data have been collected in a file, it comes to the central issue of this research project, namely, translating the Marquette statements to corresponding PTXT codes and storing these PTXT codes into the HELP patient data base.

3.2 Structure of a Marquette Statement

Before an efficient translation mechanism can be designed, it is necessary to first understand all the possible structures of a Marquette statement . As mentioned in the previous chapter, 303 Marquette interpretations exist in its library. Unlike an old HELP interpretive code which can only appear by itself in a statement or have some associated modifiers , each of the Marquette interpretations can be freely combined with other interpretations which are not necessarily modifiers. Therefore one Marquette statement can be of the following combinations:

1) A single interpretation such as ABNORMAL ECG

2) An interpretation plus one or several modifiers such as INFERIOR INFARCT, POSSIBLE, AGE UNDETERMINED

3) Several interpretations plus one or several modifiers such as SINUS BRADYCARDIA FIRST DEGREE AV BLOCK WITH OCCASIONAL VENTRICULAR PREMATURE COMPLEXES

As shown in the third statement, although SINUS BRADYCARDIA and FIRST DEGREE AV BLOCK are independent codes in the library, if the Marquette

LDS HOSPITAL

SMITH, CONNIE

ID: 894502900 LOC: EKG

03FEB40 IN   LB CAU FEM

MED:

OPT: 02 BP: 138/90 RM W454

ECG TAKEN: 08-APR-88 11:55

VENT. RATE   62   BPM

PR INTERVAL   204   MS

QRS DURATION   88   MS

QT/QTC   420/478   MS

P-R-T AXES   66 30 39

NORMAL SINUS RHYTHM

NORMAL ECG

WHEN COMPARED WITH ECG OF 01-MAR-88 20:10,

PREMATURE SUPRAVENTRICULAR COMPLEXES ARE NO

LONGER PRESENT

CW

REFERED BY: HORTON RO MI   REVIEWED BY: KENT J. BLACK

	PA	PPA	QA	QD	RA	RD	SA	SD	RPA	RPD	STJ	STM	STE	TA	IPA
V1	-68	0	0	0	68	25	390	40	800	71	4	-18	-48	-152	0
V2	-58	0	0	0	102	39	307	27	341	70	36	6	-8	0	0
V3	34	0	0	0	239	38	654	37	341	61	-4	-29	-53	-175	0
V4	39	0	0	0	698	45	742	91	0	0	-29	-21	-25	-45	0
V5	29	0	0	0	810	46	649	90	0	0	-35	-24	-15	0	0
V6	39	0	0	0	717	47	527	89	0	0	-30	-17	-4	63	0
I	58	0	48	16	722	57	278	63	0	0	-12	18	45	232	0
AVL	-19	24	78	22	722	58	214	56	0	0	0	18	36	183	0
I	87	0	0	0	346	44	458	92	0	0	-23	1	21	109	0
AVF	68	0	0	0	151	35	537	101	0	0	-15	-7	0	0	0
II	48	0	0	0	141	27	791	61	151	48	-10	-17	-23	-131	0

SMITH, CONNIE

ID: 894502900 LOC: EKG

03FEB40 IN   LB CAU FEM

MED:

OPT: 02 BP: 138/90 RM W454

ECG TAKEN: 08-APR-88 11:55

VENT. RATE   62   BPM

PR INTERVAL   204   MS

QRS DURATION   88   MS

QT/QTC   420/478   MS

P-R-T AXES66 30 39

Figure 3. Data received from the MUSE system.

system thinks they are appropriate suggestions for one manifestation, the MUSE would pack them into one statement and transmit all the information in one line. For a human reader, it is not difficult to distinguish different message segments in a line since semantic meaning of each word and syntactical structure of English text are already well understood. But for the computer to know the fact that different segments comprise one statement requires more maneuvers.

3.3 Language Processing

To communicate with computers by means of a language has long been the research scope for artificial intelligence researchers. As the ECG interpretations generator, Marquette produces English statements that the Tandem computer must understand. Fortunately, compared with other natural language producers, Marquette has only 303 fixed sets of interpretations it can use to create the various messages. Although there is no limitation on the messages Marquette can generate, the task of understanding Marquette language is narrowed down to comprehending the different segments contained in each statement since each segment is from the Marquette library. Once the components of a Marquette statement are understood, their corresponding PTXT codes can be stored into HELP. If this is completed correctly, the entire Marquette message is successfully integrated into HELP and becomes part of the patient record.

After the structure of Marquette statements is understood, a strategy designed to analyzed the information contained in a Marquette statement would be developed. In the literature, many researchers have dealt with processing input of a specific topic or format. Some of them have

constructed parsers according to specific grammars and pattern-matching rules that initiate the transformation of the input strings. [10] Though different in detailed pattern matching schemes, many programs designed for parsing statements of restricted structure have built an internal memory that stored all the general syntactic or semantic structures of the language. With the help of a built-in model, the program can use pattern-matching to either extract the key idea or to analyze the underlying constituents of the sentence in process. In this research a strategy with similar principles, namely creating an internal storage memory and following a pattern-matching scheme, is designed to parse the Marquette statements. However, since every Marquette statement consists of segments listed in its own library, the issue is further simplified to a matching procedure without involving any syntactic pattern recognition or semantic understanding process.

In this research project, a special parsing technique was designed that involves building an internal Marquette-PTXT library and a word dictionary. The Marquette-PTXT library provides a connection between each standard Marquette interpretation and its associated PTXT codes. The word dictionary is a file which displays information about a word's occurrence in the Marquette interpretations. The information may include the occurring frequency of the word as well as the interpretations in which the word is found . The word dictionary provides clues to the Marquette interpretations that might constitute the statement in study. When each constituent segment is recognized, its representative PTXT codes are captured in the Marquette-PTXT library. The following sections will illustrate this process in full detail.

3.4 Internal Marquette-PTXT Library

To connect a Marquette interpretation to its corresponding PTXT can be achieved by building an internal library which provides the linkage between each Marquette message and its associated PTXT. The library was created as a key-sequenced file which functions as the internal matching table as the one in the old ECG automated system. It differs from the old table in that the latter only provided a one-to-one link between an interpretation and its PTXT, but the library built here allows one-to-many links if a single Marquette interpretation is equivalent to the combination of many PTXT codes or modifiers. However, in terms of retrieval speed and efficiency, a one-to-one relation table is still an optimal choice although many interpretations do have one-to-many connections with their PTXT codes.

Table 1 shows the proposed one-to-one relation table which, in reality, accommodates both one-to-one and one-to-many relationships. In this table, every entry has just one attribute, that is, the PTXT representatives. All the PTXT codes for the Marquette messages belong to data class 3 and field code 64 and differ in their frame and frame modifier numbers. Since all the codes have an identical data class and field code number, it is sufficient to identify each code with its frame and frame modifier numbers. For example, for the message "NONSPECIFIC T WAVE ABNORMALITY", its PTXT will be simplified to 31 0 instead of the complete 3 3 64 31 0 0 0 0. For the Marquette interpretation like "ST ABNORMALITY", which does not have an exact match in the current PTXT codes, a new code created for it in frame 101 and a frame modifier number 82 will be assigned to it. It ends up with a code of 101 82 in the table. Other Marquette interpretations are actually modifiers and their associated PTXT will be block modifiers in block 64.

Table 1. An example of the Marquette-PTXT library

inter-pretation #	Marquette interpretation	PTXT codes
1	NONSPECIFIC T WAVE ABNORMALITY	31 0
2	T WAVE INVERSION	81 0
3	ST ABNORMALITY	101 82
4	HAS REPLACED	+140
5	NO LONGER PRESENT	+8
6	MARKED	+32
7	POSSIBLE	+13
8	NONSPECIFIC T WAVE ABNORMALITY NO LONGER EVIDENT IN	31 0+8
9	NONSPECIFIC T WAVE ABNORMALITY HAS REPLACED INVERTED T WAVES IN	31 0+140,81 0
10	MARKED ST ABNORMALITY, POSSIBLE ANTEROSEPTAL SUBENDOCARDIAL INJURY	101 82+32+13+101+109+100

For these modifying Marquette interpretations, their PTXT attributes in the library are preceded by a plus sign and the format is simplified to "+modifier number" in the library. Modifiers like "PRESENT", "MARKED", "POSSIBLE", and "HAS(HAVE) REPLACED" in Table 1 are good examples.

In addition to the Marquette entities that represent one interpretation or modifier and have exactly one corresponding PTXT, many Marquette interpretations can not be fully expressed by a single PTXT code. Those interpretations may contain meanings equivalent to a combination of several regular PTXT plus some modifiers. These Marquette interpretations are said to have a one-to-many relationship with their PTXT codes which need a special arrangement. An interpretation like "NONSPECIFIC T WAVE INVERSION NO LONGER EVIDENT IN" in Table 1 is actually a combination of an "81 0" for NONSPECIFIC T WAVE INVERSION and a "+8" for NO LONGER PRESENT. In the Marquette-PTXT library a message like this will have its corresponding PTXT and modifier codes listed side by side as its attribute. For interpretations equivalent to a combination of several PTXT codes, a comma is set between two segments of PTXT codes. If the parsing software encounters a comma, it knows that the following segment is a new piece of PTXT unit which might be a single PTXT or a PTXT combined with some modifiers. As shown in Table 1, an interpretation like "NONSPECIFIC T WAVE ABNORMALITY HAS REPLACED T WAVE INVERSION IN" displays a dual meaning structure. It would have an attribute composed of two PTXT groups representing "NONSPECIFIC T WAVE ABNORMALITY HAS REPLACED" and "T WAVE INVERSION" respectively and separated by a comma. The last entity in Table 1 shows an interpretation having another kind of combination. In this interpretation, the major message is "MARKED

ST ABNORMALITY". What follows next is an etiological suggestion composed of a string of modifiers. If an attribute contains several modifiers, these modifiers are listed one after another with a plus sign preceding each modifier number. It should be noted here that words like "ANTEROSEPTAL", "SUBENDOCARDIAL", and "INJURY" do not exist in either the Marquette or the HELP coding systems. However, these words are used repetitively in all statements related to abnormal ST segments and T waves. It is more convenient to treat these anatomic descriptions as modifiers so that fewer PTXT codes need to be created for interpretations which might contain the different major messages but differ in some frequently appearing anatomic locations.

Finally, each entity in the library has an interpretation number associated with it. The interpretation number, which consists of 5 digits, functions as the primary key and is used by the parsing software for fast location of the interpretation desired.

3.5 Word Dictionary

The word dictionary is a tool which facilitates the parsing software in distinguishing and understanding the components of a Marquette statement. The parsing algorithm will be discussed in later sections. Here attention will be focused on the structure and content of the dictionary.

The word dictionary enlists all the words participating in the Marquette interpretations. A program constructed the dictionary by examining each Marquette interpretation listed in the Marquette-PTXT library. By extracting every word from an interpretation, the software searches through the library to find if that word is contained in other interpretations. If it does, the software

increments the counter for the appearances of that word in the library and remembers the interpretation number of the interpretation that also contains the word. Eventually, all the words in the library are searched and compared and a dictionary file is built. The dictionary is also a key-sequenced file which contains three fields, namely the word, the number of interpretations in which the word appears, and the interpretation numbers. In this file the first field serves as the primary key. Table 2 shows an example of the word dictionary generated from Table 1.

After the Marquette-PTXT library and the word dictionary were built, a parsing algorithm was designed to utilize them in understanding a Marquette statement. The algorithm consists of three steps:

1) Do a word by word comparison,

2) Refer a resulted interpretation number back to the library, and finally,

3) Process the PTXT part of the record referred to by the interpretation number and store the pertinent PTXT codes and associated modifiers into the HELP system.

Each of these steps will be described separately in the following section.

3.6 The Parsing Algorithm

When a Marquette-Tandem data communication is successfully completed for one patient record, all the data lines are entered into an entry-sequenced file and the parsing software starts to examine each word contained in the statements. Each data line is one record in the file. As shown in Figure 3, each Marquette statement follows the patient demographic or measurement data and always begins at the 31st or the 33rd byte of the record. Usually one patient record includes at least 12 data lines;

Table 2. An example of the Word Dictionary

Word	number of inter-pretations	interpretation number
ABNORMALITY	5	1 3 8 9 10
ANTEROSEPTAL	1	10
EVIDENT	1	8
HAS	2	4 9
IN	2	8 9
INJURY	1	10
INVERSION	1	2
INVERTED	1	9
LONGER	2	5 8
MARKED	2	6 10
NO	2	5 8
NONSPECIFIC	3	1 8 9
POSSIBLE	2	7 10
PRESENT	1	5
REPLACED	2	4 9
ST	2	3 10
SUBENDOCARDIAL	1	10
T	4	1 2 8 9
WAVE	4	1 2 8 9
WAVES	1	9

however if more than 12 statements are issued, another 12 lines are allocated with the leading patient demographic and measurement data repeated for the second set of the 12 lines. To determine if one data line contains any interpreting message, the parsing algorithm starts examining the 31st and the 33rd bytes of each line except the 12th and the 24th record which contain the referring and confirming physician names. If a character is found at the 31st or 33rd byte of a record, it continues to read in the characters until a space is encountered. After the first word is read in, the software specifies the word as the key value for the procedure KEYPOSITION. KEYPOSITION is called to search through the primary key fields in the word dictionary and returns the record whose primary key matches the key value exactly. When the record is read into memory, the software examines the content of that record, remembering the number of interpretations and those interpretations that contain the word in study. It then proceeds using the same procedure to examine the second word in the record. After the first two words' information are obtained, the software compares the interpretation numbers for these two words and extracts the common interpretations. As can be seen, if these words are from the same library interpretation, there would exist at least one common interpretation number. With the common interpretation numbers found, the software continues to process the third word, but this time the extracted common elements are compared against the newly obtained interpretation numbers of the third word. This process continues until no more common elements can be found. At this stage, the common interpretation numbers found in the previous comparison are held as the candidates of interpretations that possibly participate in the statement in question. If only one common

element exists from the previous comparison, the value of that element is used as a key value which a KEYPOSITION procedure would then use to find the record with the same primary key value in the Marquette-PTXT library.

The common element is a clue which is to be referred back to the Marquette-PTXT library in finding the record containing the Marquette interpretation which is part of the statement. When the corresponding record is found in the library, the Marquette interpretation of that record is checked against the statement. If in the statement, starting from the first character of the first word where the word by word comparison begins, there exists a segment that matches the Marquette interpretation of the record, the parsing process is declared as a success. The length in unit of bytes of the segment is then computed and added to the starting position where the parsing process begins so that the parsing software knows where to start for the next process.

If a parsing is successful, the PTXT code part of the library record is further analyzed by the software. The software examines the string to find the frame number and frame modifier number. If at the same time some plus sign is detected, the software knows the following number is a block modifier. The software then deposits the frame number and the relevant block modifiers into a buffer. After the next parsing has been completed, the software compares the frame number of the new PTXT just obtained with the one in the buffer. If they are different, a HELP utility software called PACK^TYPE^3 is called to pack the previous data in the buffer into a data string. Another utility DATAUP is evoked next to store this string into the patient's data file. However, if the next parsing submits a PTXT string

consisting of only block modifiers, the software will accumulate those modifiers into the buffer until either a different frame number appears or an end-of-line is encountered for the statement.

An example can be given here to illustrate the process of parsing a Marquette statement. "PREMATURE SUPRAVENTRICULAR COMPLEXES ARE NO LONGER PRESENT" is a very typical Marquette statement which is a combination of three Marquette library terms "PREMATURE SUPRAVENTRICULAR COMPLEXES", "ARE NO LONGER", and "PRESENT". The last two are Marquette modifiers which can be used in association with many interpretations. These three segments are to be distinguished and their PTXT codes will be packed into one string by using the technique mentioned above. Figure 4 displays the statement's constituent words and the corresponding records obtained by KEYPOSITION in the word dictionary. It shows that the parsing position starts at the 31th byte of the message record. The patient demographic and measurement data contained in the first 30 bytes are valuable in locating a patient's file in the HELP system but are not involved in the parsing process. Figures 5-7 show the intermediate processes and the result of the word by word comparison. Figure 5 shows that among the interpretation of the first and the second words, only one common interpretation exists. This interpretation number is used to compare with the interpretations for the third word and is found also existing in that group. When the process continues to the fourth word, no more common element is found. At this stage, the common interpretation number found for the third, the second, and the first word is used as an index to point back to the library. The PTXT content which includes a frame number 101 and a frame modifier 62 is stored in the buffer

A Marquette statement from the message file

31th byte

PREMATURE SUPRAVENTRICULAR COMPLEXES ARE NO LONGER PRESENT

A   B   C

1st parsing
position

2nd parsing
position

3rd parsing
position
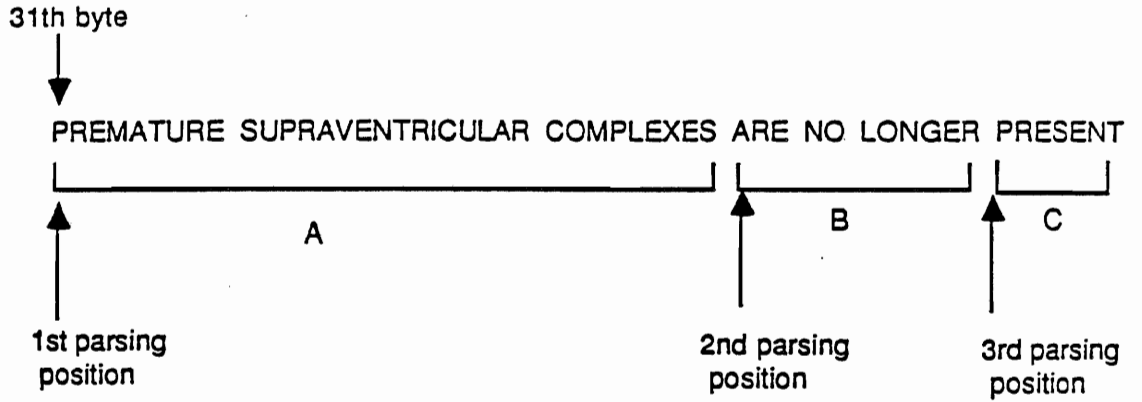
word dictionary

word	# of inter-pretations	interpretation
PREMATURE	10	13 21 30 173 322 327 328 330 453 455
SUPRA-VENTRICULAR	6	6 25 26 27 327 382 426
COMPLEXES	10	30 173 252 327 328 330 427 452 ...
ARE	3	166 167 296
NO	12	156 157 167 257 297 298 310 372 379 ...
LONGER	8	167 257 297 298 310 372 379 415
PRESENT	3	310 323 378
...	...	...

Figure 4. A Marquette statement and its relevant
information in the Word Dictionary.

Marquette-PTXT library

"PREMATURE"

inter-pretation #	Marquette	PTXT
...	...	...
327	PREMATURE SUPRA-VENTRICULAR COMPLEXES	101 62
...	...	...

327

"SUPRAVENTRICULAR"

"COMPLEXES"

327

"ARE"

327

sector number= 101

sector modifier number=62

buffer

Nill
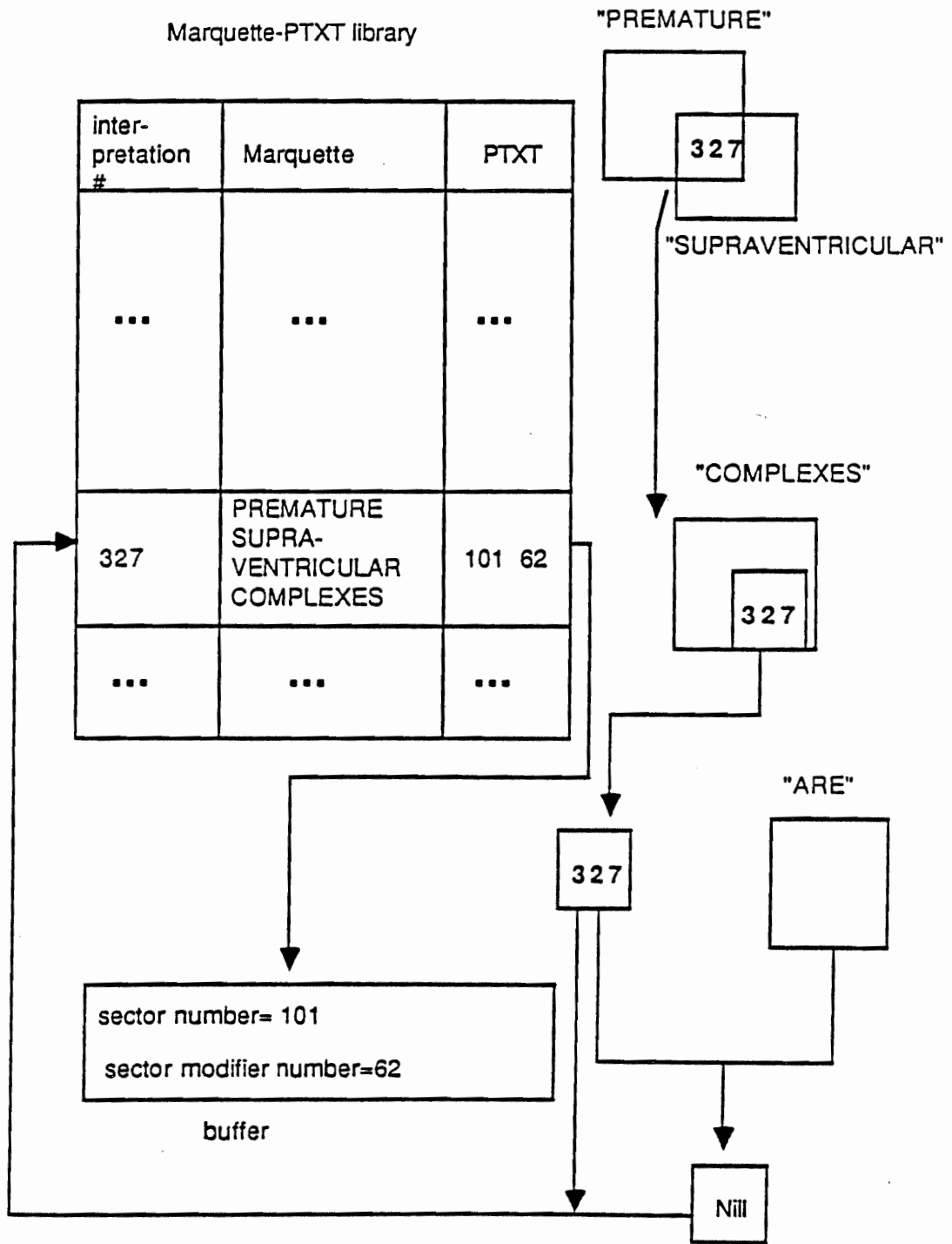
Figure 5. The first stage of the parsing process.
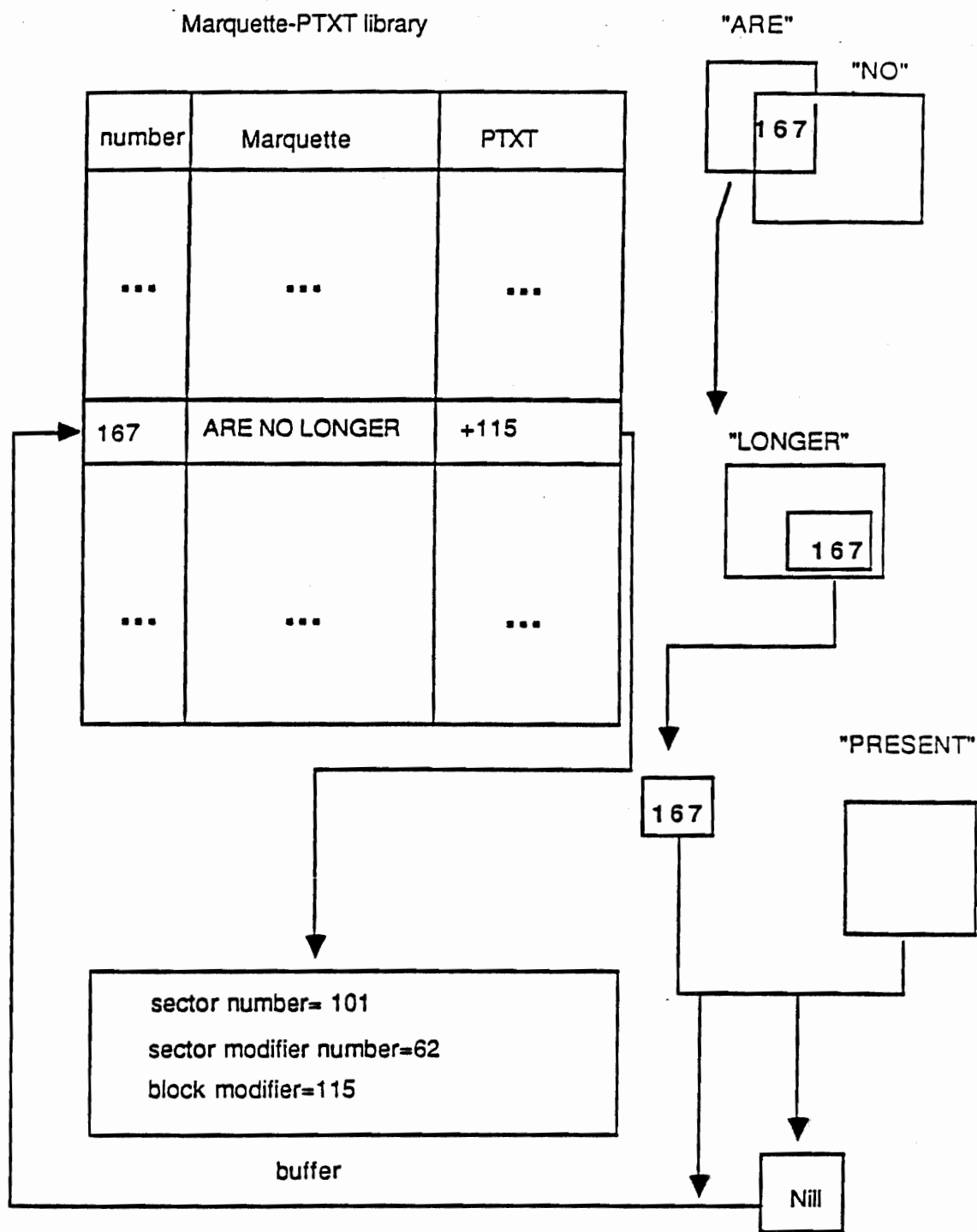
Figure 6. The second stage of the parsing process.

"PRESENT"

310
323
378

end-of-line

323

completely
match
message
segment
in the targed
line

Marquette-PTXT library

...	...	...
323	PRESENT	+7
...	...	...

sector number= 101
sector modifier number=62
block modifier1=115
block modifier2=7

PACK^TYPE^3

Type 3 data string

DATAUP

Patient file
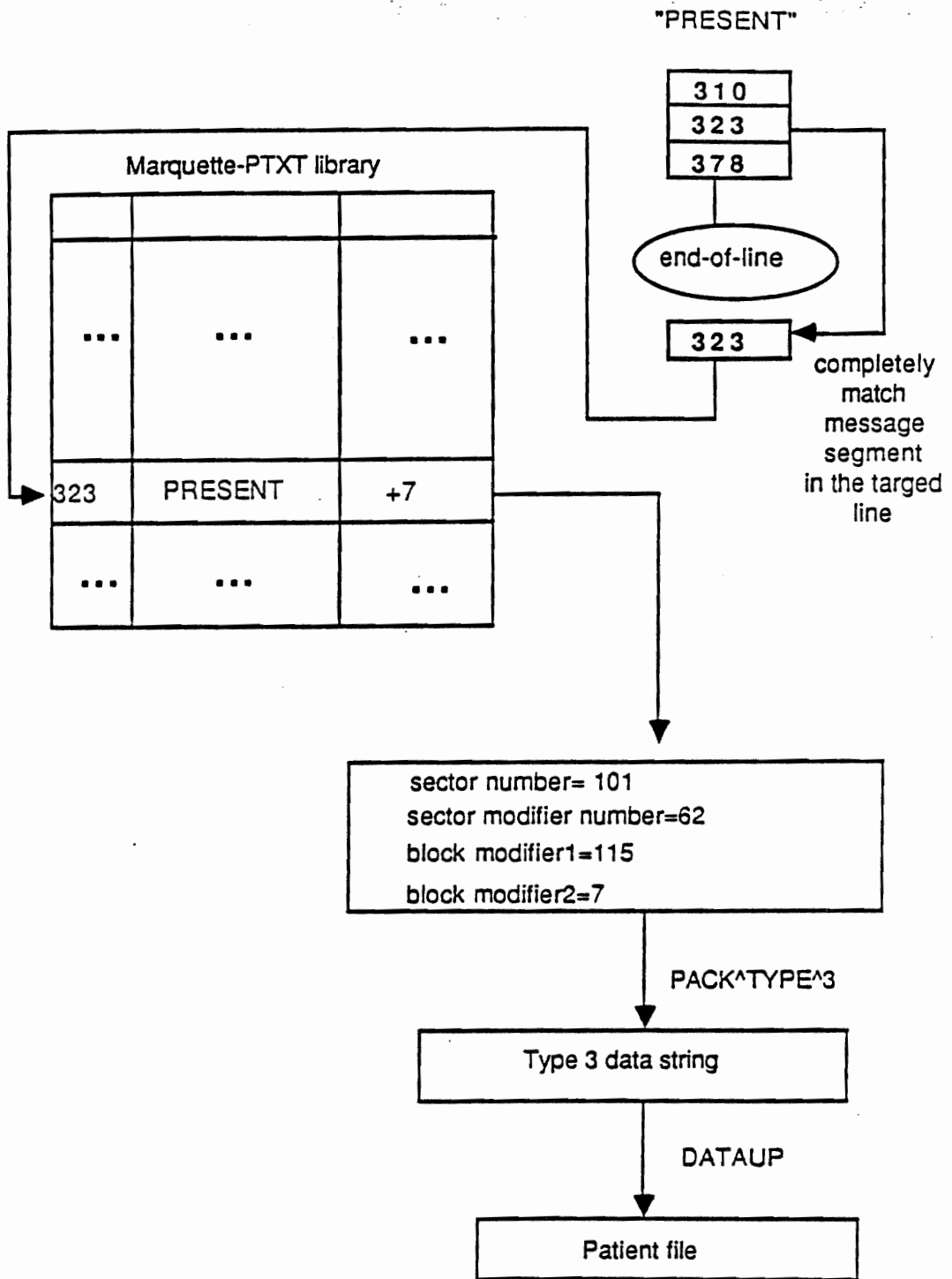
Figure 7. The final stage of the parsing process.

and the parsing position is forwarded to the beginning of the fourth word. In Figure 6 the word-by-word comparison continues on for the fourth and the fifth word, and interpretation 166 is the only common element. When the comparison is furthered along to the last word, no more common interpretation is found and the PTXT part of interpretation 166 is checked. Since the plus sign in front of number 144 indicates this PTXT stands for a modifier, the modifier is treated as part of the previous statement and deposited into the string buffer. The parsing position now is located on the last word in Figure 7. Because end-of-line is reached at this stage, no more comparison can be made and all the interpretations referred by the word "PRESENT" are checked to see which completely matches this segment. Apparently, only the interpretation containing only the word itself fulfills this requirement. Since the PTXT part of this interpretation is also a modifier, it is sent into the buffer as the second modifier for the first statement. At this moment, the parsing process is completed. The PTXT string contained in the buffer is packed together and sent to the DATAUP utility for storage into the patient's file.

In addition to dealing with statements generated completely from the Marquette statement library, the parsing algorithm needs to handle the freetext entry. The Marquette ECG editing utility allows the entry of a statement not encoded in the system. The physician can simply write on the preliminary report any statement he or she prefers. The technician, instead of entering a code in the system, types in the free-text statement. The parsing algorithm detects a freetext message if during a word-by-word comparison, the KEYPOSITION fails to find a word in the word dictionary. If this happens, the parsing algorithm resolves it by depositing the whole statement into the

buffer, computing the number of the ASCII characters in the statement, and calling the HELP utility PACK^TYPE^1. The reason for this is that PACK^TYPE^1 has the capability of packing the freetext data. The user simply informs this utility of the address of the buffer, the length of the text, and the special delimiter indicating the freetext nature of the string. After the freetext message is packed, DATAUP is called as usual for data storage.

3.7 Parsing Failures and Solutions

The parsing algorithm proposed does have some potential problems. For example, in the Marquette code library there exist three independent interpretations, namely, "RIGHT VENTRICULAR HYPERTROPHY", "RIGHT VENTRICULAR HYPERTROPHY WITH REPOLARIZATION ABNORMALITIES", and "WITH 2:1 A-V CONDUCTION". A statement which combines the first and the third code above would form a statement "RIGHT VENTRICULAR HYPERTROPHY WITH 2:1 A-V CONDUCTION". If the parsing algorithm is used, as shown in Figure 8, the resulting interpretation number after the word by word comparison would be 353. This represents the second interpretation mentioned above. When this number is referred back to the library, the statement represented by this interpretation number would not match the targeted message segment and the parsing algorithm fails to handle this segment successfully.

This problem arises because many Marquette modifiers start with the word "WITH", a word which also appears frequently in other regular interpretations. Similarly, words like "CONSIDER", "CONSISTENT", "PRESENT", etc. may cause same kind of problem.

In order to compensate for this deficiency, a simple technique was

A Marquette statement

RIGHT VENTRICULAR HYPERTROPHY WITH 1ST DEGREE A-V BLOCK

67
114
115
353
354
359
361

114
115
353
354
359

353

0

statements fail
to match
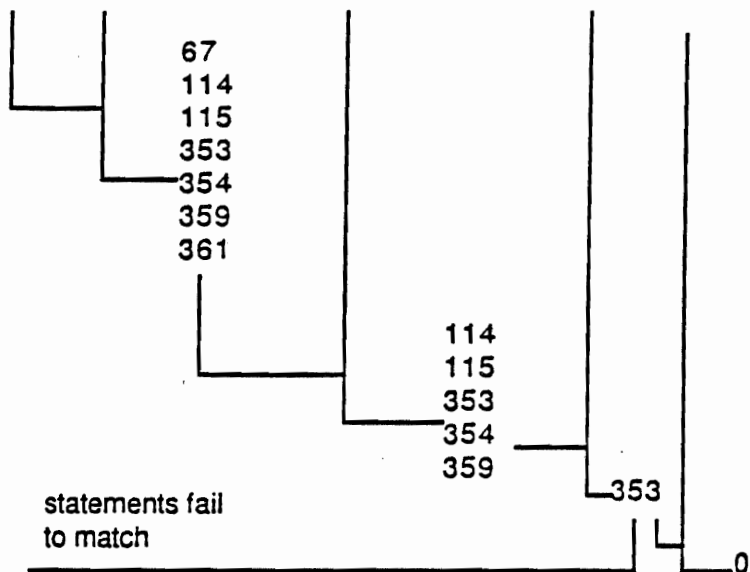
Marquette-PTXT library

	Marquette	PTXT
353	RIGHT VENTRICULAR HYPERTROPHY WITH REPOLARIZATION ABNORMALITIES	15 0+110
...	...	...

Figure 8. An unsuccessful parsing process.

designed. The compensating method remembers the common interpretation numbers obtained from comparing the first two words of every message segment. It then continues on for the rest of the words as usual. If the library interpretation represented by the final common interpretation number does not match the segment, the common interpretation numbers from the first two words will be used as the final interpretation numbers. Most of the time every library interpretation contains at least two words. It seems practical to rebuild the correct interpretation from the first two words. Figure 9 shows how the technique solves the problem in Figure 8. However, the Marquette library also contains non-modifier interpretations composed of just one word like "LVH". If "LVH" is modified by a "WITH 2ND DEGREE A-V BLOCK", then the same problem would arise since there exists a library interpretation "LVH WITH ST AND T WAVE ABNORMALITIES". When this occurs, even the compensating method fails. In this case, the problem is resolved by using the first word's referencing interpretation numbers as final numbers and referring all of them back to the Marquette-PTXT library. This is the worst case since all the interpretations referred to by the first word needed to be checked. Also, if there are many referencing interpretations, too much computer time would be taken. Therefore, it was decided that when a parsing process fails for the first time, the common interpretation numbers of the first two words will be used first. If the second try also fails, then each interpretation of the first word would be checked.

There are situations in which even the last try fails when all the interpretations referred to by the first word do not provide an interpretation matching the message segment. This would occur if a physician writes down an interpretation which is not coded in the system but all the words of this

A Marquette statement

RIGHT VENTRICULAR HYPERTROPHY WITH 1ST DEGREE A-V BLOCK

2ND PARSING POSITION

67
114
115
353
354
359
361

Marquette-PTXT library

	Marquette	PTXT
67	RIGHT VENTRICULAR INFARCT ...	
(114)	RIGHT VENTRICULAR HYPERTROPHY	
115	COMBINED RIGHT AND LEFT VENTRICULAR...	
353	...	
354	RIGHT BUNDLE BRANCH BLOCK OR RIGHT VENT...	
359	, PLUS RIGHT VENTRICULAR HYPERTROPHY ...	
361	RSR' OR QR PATTERN...RIGHT VENTRICULAR...	

Figure 9. An algorithm for dealing
with parsing failures.

statement happen to be in the word dictionary. One such example is shown in Figure 10. If the last try fails, then it is decided that the whole line would be a physician comment and the whole sentence is treated as a freetext message.

3.8 Some Measurement Data

The parsing algorithm is also designed for analyzing the Marquette measurement data. For each individual ECG, measurements like ventricular rate, PR interval, QRS duration, QT and QTC ratio, and P, R, T axes are also valuable information for the medical personnel. In order to store these data, new type 1 PTXT codes are created for them. These PTXT codes are organized under data class 3 and field code 64 and they have noun numbers ranging from 16 to 23. Since in each ECG report all these data appear at the first half of the 8th, 9th, 10th, 11th, and 12th data lines as shown in Figure 3, it is not difficult to handle and store these data. The analyzing software just captures the numbers from those locations and stores each of them. As mentioned earlier, the measurement matrix data, which include information about 15 median complexes simultaneously recorded from 12 leads, are needed for other research purposes in the hospital and they are also transmitted for each ECG report. The measurement matrix is always appended at the end of a report, and each measurement also appears at a fixed position in each transmitted patient record. These data are also handled in the same way and are stored as type 1 data with the same data class and field code as the measurements mentioned above. However, since each complex is recorded in 12 leads at the same time, there are 180 (15 * 12 = 180) pieces of data altogether. If a PTXT code is to be made for

Physician comment

NO CHANGE OCCURRED

Treat the whole
line as a freetext
message

157

0

statements
do not
match

157	NO SIGNIFICANT CHANGE WAS FOUND	

interpretations referenced by "NO"

156	NO PREVIOUS ECG AVAILABE	
157		
167	ARE NO LONGER	
257	FLAT T WAVES NO LONGER...	
297	IS NO LONGER	
298	NONSPECIFIC T WAVES NO ...	
310	NO LONGER PRESENT	
372	ST NO LONGER...	
379	ST NO LONGER ELEVATED...	
415	T WAVE INVERSION NO...	
475	... ASSUME NO REVERSAL	
482	NO IDENTIFIABLE ATRIAL...	

No
matches

Figure 10. A freetext message with every word
contained in the Word Dictionary.

each one of them, too much space in the PTXT dictionary is going to be needed. To avoid wasting memory space, one can make the PTXT codes for describing the 12 lead sources as field code modifiers so that whenever a value of a complex is captured, it is packed with a modifier which indicates from which lead it is generated. In this way, the PTXT codes needed for the matrix data are reduced to 27 which includes noun numbers ranging from 1 to 15 and field code modifiers from 1 to 12.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Performance of the Communication and Parsing Software

When a patient's record has been successfully transferred from the

MUSE system, the physician can review the relevant ECG data from the

nursing stations by calling a nursing ECG reporting utility written in PAL

(PTXT Application Language). Figure 11 shows a typical patient record

transferred from MUSE. Figure 12 displays the report generated by the

nursing utility after the MUSE report in Figure 11 has been processed by the

parsing software. By comparing the messages contained in these two

reports, one can find that all the MUSE ECG interpretations in Figure 11 have

been translated into some semantically equivalent expressions in Figure 12.

Ideally, the communication and parsing software should be able to instantly

and accurately analyze data from the MUSE system so that the physician

could have a prompt access to the MUSE ECG interpretations.

The communication and parsing software was implemented in March,

1988. This software is ready 24 hours a day to receive and process ECG

data from the MUSE system. When a patient's ECG is taken, it has to be

overread and confirmed by a cardiologist. After a technician enters the

confirmed report, it is immediately sent to port 231 of the Tandem computer.

It has been observed that after the connection was built between the MUSE

LDS HOSPITAL   NORMAL SINUS RHYTHM FIRST DEGREE AV BLOCK

STROKER, WALLACE   WITH OCCASIONAL PREMATURE

ID: 449873200 LOC: EKG   SUPRAVENTRICULAR COMPLEXES

21JUN38 IN LB CAU MALE   ST & T WAVE ABNORMALITY, CONSIDER

MED: NONE   INFEROLATERAL ISCHEMIA OR DIGITALIS EFFECT

LOC: 0 ROOM: W470   CANNOT RULE OUT INFERIOR INFARCT, AGE

OPT: 10 BP: RM: W555   UNDETERMINED

ECG TAKEN: 03-MAY-88 14:20 ABNORMAL ECG

VENT. RATE 96BPM   WHEN COMPARED WITH ECG OF 01-MAY-88 20:14

PR INTERVAL: 165 MS   T WAVE INVERSION NOW EVIDENT IN INFERIOR LEADS

QRS DURATION 90 MS   MS

QT/QTC 392/457 MS

P-R-T AXES 20 27 43   REFERRED BY: JOHN S REVIEWED BY: KEVIN COTE M. D.

Figure 11. A MUSE ECG report.

LDS HOSPITAL ECG REPORT

STROKER, WALLACE   AGE: 50 SEX: M NO. 43234325 DR: TOWNER D. RM: W555

ECG DATA

** ***   5/3/88 14:20

VENT. RATE = 96 BPM

PR INTERVAL = 165 MS

QRS DURATION = 90 MS

QT/QTC = 392/457 MS

P AXIS = 20

R AXIS = 27

T AXIS = 43

NORMAL SINUS RHYTHM

FIRST DEGREE AV BLOCK WITH OCCASIONAL

PREMATURE SUPRAVENTRICULAR COMPLEXES

ST T WAVES ABNORMALITIES, INFEROLATERAL ISCHEMIA CONSIDER

DIGITALIS EFFECT SUSPECT

INFERIOR INFARCTION CANNOT BE EXCLUDED AGE UNDETERMINED

ABNORMAL ECG

WHEN COMPARE WITH ECG OF 5/1/88 20:14

T WAVE INVERSION PRESENT INFERIOR LEADS

*** END OF REPORT ***

Figure 12. A HELP ECG report.

and the HELP systems, the communication process was terminated several times due to the maintenance needs of the Tandem computer. Whenever the Tandem failed to respond for a certain period of time, the MUSE system terminated the communication and kept sending logon requests until the Tandem was up again. During the down period, patient records were accumulated in the MUSE buffer. When communication resumed, all records were sent without any loss of data.

To precisely translate the MUSE ECG interpretations into HELP expressions and permanently store them into the patient data base was the primary goal of this project. Since the implementation of the parsing software, more than 3000 patient records have been transferred. In order to understand how accurate the parsing software is in performing the translation task, 500 patients were randomly selected, and their ECG data stored in the HELP data base were manually compared with the original MUSE ECG reports. It was found that on average, each patient record contains 5 statements. Among these 500 patient records, all of the statements except three had their MUSE ECG interpretations transformed to semantically corresponding PTXT strings. The three statements in error contain the same modifier "OCCASIONAL" for which the corresponding PTXT code in the Marquette-PTXT library was incorrectly entered.

4.2 Discussion

According to the performance of the communication and parsing software, it is sufficient to say that the communication protocol and the parsing algorithm have been well defined and satisfy the need of integrating the MUSE ECG interpretations into the HELP system. The communication

protocol allows the communication between these two systems to proceed after abnormal terminations. The parsing algorithm, with the help of the Marquette-PTXT library and the word dictionary, is able to analyze a Marquette statement and substitute it with appropriate PTXT representations.

Basically, what the parsing algorithm does is try to map the message segments contained in a statement with a fixed set of codes. Therefore if all the messages contained in a statement are from the listed Marquette interpretations, each of the messages should be captured by the parsing software and its meaning be completely presented to the reviewing physician without any distortion. As a result, it should be noted that if a message is not specified in the interpretation library, it would be stored as physician's freetext comment. This strategy has its limitations since it would treat any message not in the library as freetext comment even when the message contains similar information as one of the codes in the library. For example, the statement in Figure 10 is a freetext which resembles a Marquette interpretation "NO SIGNIFICANT CHANGE WAS FOUND". Though the overread physicians seldom use a freetext message instead of an existing standard code, it is considered the limitation of the parsing software since it does not have the flexibility as some natural language processing techniques in extracting messages from statements of various formats.

4.3 Conclusion

Interfacing the MUSE ECG system to HELP is the ultimate goal of this research project. Two major problems encountered in accomplishing this goal were defining the PTXT codes for the MUSE interpretations and understanding the MUSE statements. The first problem was dealt with by

creating new type 3 PTXT codes for the Marquette interpretations. For the Marquette codes that could be substituted by the existing PTXT codes, the equivalent PTXT expressions would be used. In this process care was taken to avoid the problem of duplicating data items already existing in the PTXT dictionary.

For understanding the Marquette statements, a Marquette-PTXT library and a word dictionary were built to help the parsing algorithm in perceiving the Marquette standard interpretations. With the aid of these built-in structures, it has been observed that the parsing software can successfully map the messages contained in a statement with the fixed library codes and store these messages into the HELP patient data base.

Judging from the performance of the communication and parsing software, It is sufficient to say that although the parsing algorithm has the limitations when dealing with freetext messages, this interfacing software is constantly ready to receive MUSE ECG data and abstract the correct information for the HELP system. According to this, the goal of integrating the MUSE system to the HELP system has been successfully accomplished.

APPENDIX A

MARQUETTE INTERPRETATIONS AND CORRESPONDING PTXT EXPRESSIONS

Marquette	HELP
1. ABNORMAL ECG	ABNORMAL ECG
2. NORMAL ECG	NORMAL ECG
3. SINUS PAUSE	WITH SINUS PAUSE
4. NONSPECIFIC T WAVE ABNORMALITY	NONSPECIFIC T WAVE ABNORMALITIES, (FLAT OR LOW VOLTAGE)
5. T WAVE INVERSION IN	T WAVE INVERSION
6. LVH	LEFT VENTRICULAR HYPERTROPHY
7. RIGHT VENTRICULAR HYPERTROPHY	RIGHT VENTRICULAR HYPERTROPHY
8. BIVENTRICULAR HYPERTROPHY	COMBINED RIGHT AND LEFT VENTRICULAR HYPERTROPHY
9. LEFT ATRIAL ENLARGEMENT	LEFT ATRIAL ENLARGEMENT
10. RIGHT ATRIAL ENLARGEMENT	RIGHT ATRIAL ENLARGEMENT
11. BIATRIAL ENLARGEMENT	COMBINED RIGHT AND LEFT

		ATRIAL ENLARGEMENT
12.	VOLTAGE CRITERIA FOR LEFT VENTRICULAR HYPERTROPHY	LVH, VOLTAGE CRITERIA ONLY
13.	ANTEROSEPTAL INFARCT	ANTEROSEPTAL INFARCTION
14.	ANTERIOR INFARCT	ANTERIOR INFARCTION
15.	INFERIOR INFARCT	INFERIOR INFARCTION
16.	POSTERIOR INFARCT	POSTERIOR INFARCTION
17.	LATERAL INFARCT	LATERAL INFARCTION
18.	ANTEROLATERAL INFARCT	ANTEROLATERAL INFARCTION
19.	PREMATURE ATRIAL COMPLEXES	ATRIAL PREMATURE COMPLEX
20.	ELECTRONIC ATRIAL PACEMAKER	ATRIAL PACEMAKER (AOO, AII)
21.	ATRIAL TACHYCARDIA	ATRIAL TACHYCARDIA
22.	DEMAND PACEMAKER; INTERPRETATION IS BASED ON INTRINSIC RHYTHM	VENTRICULAR PACEMAKER DEMAND (VVI)
23.	AV SEQUENTIAL OR DUAL CHAMBER ELECTRONIC PACEMAKER	AV SEQUENTIAL PACEMAKER (DVI)
24.	DEXTROCARDIA	DEXTROCARDIA
25.	NO PREVIOUS ECGS AVAILABLE	NO PREVIOUS ECG RECORDED ON THIS PATIENT
26.	MULTIFOCAL ATRIAL TACHYCARDIA	MULTIFOCAL ATRIAL

	TACHYCARDIA (>100/MIN)
27. WITH INTERMITTENT ABERRANT VENTRICULAR CONDUCTION	ABBERANT CONDUCTION
28. WITH ATRIAL ESCAPE	ATRIAL ESCAPE COMPLEX(ES)
29. AGE UNDETERMINED	AGE UNDETERMINED
30. WITH ABBERATION	ABBERANT CONDUCTION
31. ••• BIFASCICULAR BLOCK ***	BIFASICULAR BLOCK (RBBB + INDETERMINATE AXIS)
32. BORDERLINE	BORDERLINE
33. IN A PATTERN OF BIGEMINY	BIGEMINY
34. THIRD DEGREE (COMPLETE) AV BLOCK	COMPLETE HEART BLOCK
35. CONSECUTIVE	CONSECUTIVE
36. AND CONSECUTIVE	CONSECUTIVE
37. ATRIAL FIBRILLATION	ATRIAL FIBRILLATION
38. CANNOT RULE OUT	CANNOT BE EXCLUDED
39. PREMATURE JUNCTIONAL COMPLEXES	JUNCTIONAL PREMATURE COMPLEX(ES)
40. JUNCTIONAL RHYTHM	JUNCTIONAL RHYTHM
41. HAS INCREASED	INCREASE
42. HAS DECREASED	DECREASE
43. IDIOVENTRICULAR RHYTHM WITH IV BLOCK	IDIOVENTRICULAR RHYTHM (<50/MIN)
44. JUNCTIONAL TACHYCARDIA	JUNCTIONAL TACHYCARDIA
45. SUPRAVENTRICULAR TACHYCARDIA	SUPRAVENTRICULAR

	TACHYCARDIA, TYPE UNDETERMINED
46. WITH JUNCTIONAL ESCAPE COMPLEXES	JUNCTIONAL ESCAPE COMPLEX(ES)
47. PROLONGED QT	PROLONGED QT/QU INTERVAL
48. LATERAL LEADS	LATERAL
49. ATRIAL FLUTTER	ATRIAL FLUTTER
50. NONSPECIFIC ST ABNORMALITY	NONSPECIFIC ST SEGMENT ABNORMALITIES
51. NONSPECIFIC T WAVE ABNORMALITY	NONSPECIFIC T WAVE ABNORMALITIES (FLAT OR LOW VOLTAGE)
52. OR DIGITALIS EFFECT	DIGITALIS EFFECT, SUSPECT
53. OLD	OLD
54. PRESENT	PRESENT
55. VENTRICULAR TACHYCARDIA	VENTRICULAR TACHYCARDIA
56. PROBABLY DIGITALIS EFFECT	DIGITALIS EFFECT, SUSPECT
57. POSSIBLE	POSSIBLE
58. VENTRICULAR FIBRILLATION	VENTRICULAR FIBRILLATION
59. , PLUS RIGHT VENTRICULAR HYPERTROPHY	RIGHT VENTRICULAR HYPERTROPHY

60. WIDE QRS TACHYCARDIA	WIDE QRS TACHYCARDIA, TYPE UNDETERMINED
61. ABNORMAL RIGHT AXIS DEVIATION	RIGHT AXIS DEVIATION
62. WITH RAPID VENTRICULAR RESPONSE	WITH RAPID VENTRICULAR RESPONSE
63. WITH 2:1 A-V CONDUCTION	WITH 2:1 CONDUCTION RATIO
64. WITH 3:1 A-V CONDUCTION	WITH 3:1 CONDUCTION RATIO
65. WITH 4:1 A-V CONDUCTION	WITH 4:1 CONDUCTION RATIO
66. WITH VARIABLE A-V BLOCK	WITH VARING CONDUCTION
67. SHIFTED LEFT	AXIS SHIFT LEFT
68. SHIFTED RIGHT	AXIS SHIFT RIGHT
69. ST DEPRESSION IN	ST DEPRESSION
70. ST ELEVATION IN	ST ELEVATION
71. BORDERLINE ECG	BORDERLINE ECG
72. WITH 2ND DEGREE A-V BLOCK (MOBITZ I)	SECOND DEGREE AV BLOCK, TYPE 1 (WENCKEBACH)
73. WITH 2ND DEGREE A-V BLOCK (MOBITZ II)	SECOND DEGREE AV BLOCK, TYPE 2 (MOBITZ)
74. WITH SINUS ARRHYTHMIA	SINUS ARRHYTHMIA
75. WITH SLOW VENTRICULAR RESPONSE	WITH SLOW VENTRICULAR RESPONSE

76. WITH VENTRICULAR ESCAPE COMPLEX	VENTRICULAR ESCAPE COMPLEX(ES)
77. WOLFF-PARKINSON-WHITE	WOLFF-PARKINSON-WHITE PATTERN
78. WITH A-V DISSOCIATION	AV DISSOCIATION, TYPE UNDETERMINED
79. WITH 2ND DEGREE SA BLOCK (MOBITZ I)	SECOND DEGREE SA BLOCK, TYPE 1 (WENCKEBACH)
80. WITH 2ND DEGREE SA BLOCK (MOBITZ II)	SECOND DEGREE SA BLOCK, TYPE 2 (MOBITZ)
81. WITH 1ST DEGREE A-V BLOCK	FIRST DEGREE AV BLOCK
82. PULMONARY DISEASE PATTERN	CHANGES CONSISTENT WITH DIFFUSE PULMONARY DISEASE
83. (RBBB AND LEFT ANTERIOR FASCICULAR BLOCK)	BIFASCICULAR BLCOK (RBBB+RAD)
84. (RBBB AND LEFT POSTERIOR FASCICULAR BLOCK)	BIFASICULAR BLOCK (RBBB+LAD)
85. LEFT BUNDLE BRANCH BLOCK	COMPLETE LEFT BUNDLE BRANCH BLOCK
86. RIGHT BUNDLE BRANCH BLOCK	COMPLETE RIGHT BUNDLE BRANCH BLOCK
87. ST ABNORMALITY	NONSPECIFIC ST SEGMENT ABNORMALITIES

88. T WAVE INVERSION IN   T WAVE INVERSION

89. ABNORMAL LEFT AXIS DEVIATION   LEFT AXIS DEVIATION

90. INDETERMINATE AXIS   INDETERMINANT AXIS

91. NORMAL SINUS RHYTHM   NORMAL SINUS
MECHANISM

92. INCOMPLETE RIGHT BUNDLE BRANCH BLOCK   INCOMPLETE RIGHT BUNDLE BRANCH BLOCK

93. SINUS TACHYCARDIA   SINUS TACHYCARDIA

94. INCOMPLETE LEFT BUNDLE BRANCH BLOCK   INCOMPLETE LEFT BUNDLE BRANCH BLOCK

95. LEFT ANTERIOR FASCICULAR BLOCK   LEFT ANTERIOR SUPERIOR FASCICULAR BLOCK

96. LEFT POSTERIOR FASCICULAR BLOCK   LEFT POSTERIOR INFERIOR FASCICULAR BLOCK

97. TRIFASCICULAR BLOCK   TRIFASICULAR CONDUCTION DEFECT

98. SINUS BRADYCARDIA   SINUS BRADYCARDIA

99. NONSPECIFIC ST AND T WAVE ABNORMALITY   NONSPECIFIC ST-T ABNORMALITIES

100. ST ELEVATION IN   ST SEGMENT ELEVATION

101. NO SIGNIFICANT CHANGE WAS FOUND   NO SIGNIFICANT ECG CHANGES SINCE

APPENDIX B

MARQUETTE INTERPRETATIONS AND THEIR EQUIVALENT HELP STATEMENTS

Marquette	HELP
1. ATRIAL FLUTTER WITH 2:1 BLOCK	ATRIAL FLUTTER, WITH 2:1 CONDUCTION RATIO
2. POSSIBLY ACUTE	POSSIBLE, ACUTE
3. MARKED SINUS BRADYCARDIA	MARKED, SINUS BRADYCARDIA
4. WITH MARKED SINUS ARRHYTHM	MARKED, SINUS ARRHYTHM
5. NONSPECIFIC T WAVE ABNORMALITY NO LONGER EVIDENT IN	NONSPECIFIC T WAVE ABNORMALITY, NO LONGER PRESENT
6. NONSPECIFIC T WAVE ABNORMALITY NOW EVIDENT IN	NONSPECIFIC T WAVE ABNORMALITY, PRESENT
7. ST NO LONGER DEPRESSED IN	ST DEPRESSION, NO LONGER PRESENT
8. ST NOW DEPRESSED IN	ST DEPRESSION, PRESENT
9. ST ELEVATION NOW PRESENT IN	ST ELEVATION, PRESENT
10. ST NO LONGER ELEVATED IN	ST ELEVATION, NO LONGER PRESENT
11. T WAVE INVERSION NOW EVIDENT IN	T WAVE INVERSION,

PRESENT

12. T WAVE INVERSION NO LONGER
EVIDENT IN

T WAVE INVERSION,
NO LONGER PRESENT

13. WITH TRANSIENT VENTRICULAR
TACHYCARDIA

VENTRICULAR
TACHYCARDIA,
NON-SUSTAINED

14. VOLTAGE CRITERIA FOR LEFT
VENTRICULAR HYPERTROPHY

LEFT VENTRICULAR
HYPERTROPHY, VOLTAGE
CRITERIA ONLY

15. LVH WITH ST AND T WAVE
ABNORMALITIES

LVH, NON-SPECIFIC ST-T
ABNORMALITIES

APPENDIX C

MARQUETTE INTERPRETATIONS AND HELP
SEMI-EQUIVALENTS

Marquette	HELP
1. WITH FUSION OR INTERMITTENT VENTRICULAR PRE-EXCITATION (WPW)	VENTRICULAR FUSION COMPLEX, WOLF-PARKINSON-WHITE PATTERN
2. WITH PREMATURE VENTRICULAR OR ABBERANTLY CONDUCTED COMPLEXES	VENTRICULAR PREMATURE COMPLEXES, ABBERANT CONDUCTION
3. INVERTED T WAVES HAVE REPLACED FLAT T WAVES IN	INVERTED T WAVE
4. UNUSUAL P AXIS AND SHORT PR, PROBABLY JUNCTIONAL TACHYCARDIA	JUNCTIONAL TACHYCARDIA, PROBABLE
5. UNUSUAL P AXIS AND SHORT PR, PROBABLE JUNCTIONAL RHYTHM	JUNCTIONAL RHYTHM, PROBABLE
6. FLAT T WAVES HAVE REPLACED INVERTED T WAVES IN	INVERTED T WAVE
7. NONSPECIFIC T WAVE ABNORMALITY HAS REPLACED INVERTED T WAVES IN	NONSPECIFIC T WAVE ABNORMALITY, INVERTED

		T WAVE
8.	INVERTED T WAVES HAVE REPLACED NONSPECIFIC T WAVE ABNORMALITY	INVERTED T WAVE, NONSPECIFIC T WAVE ABNORMALITY
9.	NONSPECIFIC T WAVE ABNORMALITY, WORSE IN	NONSPECIFIC T WAVE ABNORMALITY
10.	NONSPECIFIC T WAVE ABNORMALITY, IMPROVED IN	NONSPECIFC T WAVE ABNORMALITY
11.	ST LESS DEPRESSED IN	ST DEPRESSION
12.	ST MORE DEPRESSED IN	ST DEPRESSION
13.	ST DEPRESSION HAS REPLACED ST ELEVATION IN	ST DEPRESSION, ST ELEVATION
14.	RIGHT VENTRICULAR HYPERTROPHY WITH REPOLARIZATION ABNORMALITY	RIGHT VENTRICULAR HYPERTROPHY
15.	RIGHT BUNDLE BRANCH BLOCK OR RIGHT VENTRICULAR HYPERTROPHY	COMPLETE RIGHT BUNDLE BRANCH BLOCK, RIGHT VENTRICULAR HYPERTROPHY
16.	ST LESS ELEVATED IN	ST ELEVATION
17.	ST ELEVATION HAS REPLACE ST DEPRESSION IN	ST ELEVATION, ST DEPRESSION
18.	ST MORE ELEVATED IN	ST ELEVATION
19.	ST ELEVATION, CONSIDER EARLY REPOLARIZATION, PERICARDITIS OR INJURY	ST ELEVATION, CONSIDER,

20. ST DEPRESSION, CONSIDER SUBENDOCARDIAL INJURY OR DIGITALIS EFFECT   ST DEPRESSION, DIGITALIS EFFECT, SUSPECT

21. T WAVE INVERSION MORE EVIDENT IN   T WAVE INVERSION, PRESENT

22. T WAVE INVERSION NOW EVIDENT IN   T WAVE INVERSION, PRESENT

23. T WAVE INVERSION LESS EVIDENT IN   T WAVE INVERSION, PRESENT

24. UNUSUAL P AXIS, POSSIBLE ECTOPIC ATRIAL RHYTHM   POSSIBLE, ECTOPIC ATRIAL RHYTHM

25. ST ELEVATION, CONSIDER EARLY REPOLARIZATION   ST ELEVATION, CONSIDER

26. ST ABNORMALITY, POSSIBLE DIGITALIS EFFECT   DIGITALIS EFFECT, SUSPECT

APPENDIX D

UNIQUE MARQUETTE INTERPRETATIONS

1. *** POOR DATA QUALITY
2. *** SUSPECT ARM LEAD REVERSAL
3. WITH REPOLARIZATION ABNORMALITY
4. RIGHT V3
5. RIGHT V4
6. SUSPECT A-V CONDUCTION DEFFECT
7. ARE NOW
8. MARKED ST ABNORMALITY, POSSIBLE ANTERIOR SUBENDOCARDIAL INJURY
9. ANTEROSEPTAL LEADS
10. ANTEROLATERAL LEADS
11. (ATRIAL RATE
12. QRS AXIS
13. ACQUISITION HARDWARE FAULT PREVENTS RELIABLE ANALYSIS, CAREFULLY CHECK ECG RECORD BEFORE INTERPRETING
14. AND
15. ANTERIOR LEADS
16. BORDERLINE CRITERIA FOR
17. BASIC RHYTHM
18. BLOCK

19. CURRENT UNDETERMINED RHYTHM PRECLUDES RHYTHM COMPARISON, NEEDS REVIEW

20. CRITERIA FOR

21. WHEN COMPARED WITH ECG OF

22. (CITED ON OR BEFORE

23. COUNTER CLOCKWISE OF THE HEART, MAY INVALIDATE CRITERIA FOR VENTRICULAR HYPERTROPHY

24. CLOCKWISE ROTATION OF THE HEART, MAY INVALIDATE CRITERIA FOR VENTRICULAR HYPERTROPHY

25. COARSE

26. WITH A COMPETING JUNCTIONAL PACEMAKER

27. WARNING: DEMOGRAPHIC DATA DIFFERENT

28. QUESTIONABLE CHANGE IN INITIAL FORCES OF

29. UNUSUAL P AXIS, POSSIBLE ECTOPIC ATRIAL BRADYCARDIA

30. WITH ESCAPE BEAT

31. SERIAL CHANGES OF EVOLVING

32. WITH FREQUENT

33. HAS (HAVE) NOT CHANGED

34. HOWEVER

35. HAS (HAVE) CHANGED

36. HOWEVER IT

37. HAS REPLACED

38. MARKED ST ABNORMALITY, POSSIBLE INFERIOR SUBENDOCARDIAL INJURY

39. INCREASED EVIDENCE OF INFARCTION IN

40. INFEROPOSTERIOR LEADS

41. WITH UNDETERMINED RHYTHM IRREGULARITY

42. INFEROLATERAL LEADS

43. NONSPECIFIC INTRA-VENTRICULAR CONDUCTION BLOCK

44. IRREGULAR

45. INFERIOR LEADS

46. JUNCTIONAL BRADYCARDIA

47. UNUSUAL P AXIS AND SHORT PR, PROBABLE JUNCTIONAL BRADYCARDIA

48. JUNCTIONAL ST DEPRESSION, PROBABLY NORMAL

49. JUNCTIONAL ST DEPRESSION, PROBABLY ABNORMAL

50. FEWER LEADS EXHIBIT FLAT T WAVES IN

51. FLAT T WAVES NO LONGER EVIDENT IN

52. FLAT T WAVES NOW EVIDENT IN

53. MARKED ST ABNORMALITY, POSSIBLE LATERAL SUBENDOCARDIAL INJURY

54. LEFT ATRIAL BRADYCARDIA

55. LEFT ATRIAL TACHYCARDIA

56. LESS FREQUENT

57. MODERATE VOLTAGE CRITERIA FOR LVH, MAY BE NORMAL VARIANT

58. LARGE

59. LOW VOLTAGE QRS

60. LEFTWARD AXIS

61. LOW HEART RATE, VERIFY A-V CONDUCTION

62. LEFT ATRIAL RHYTHM

63. MINIMAL CRITERIA FOR

64. MORE LEADS EXHIBIT FLAT T WAVES IN

65. MARKED ST ABNORMALITY, POSSIBLE ANTEROSEPTAL SUBENDOCARDIAL INJURY

66. MARKED ST ABNORMALITY, POSSIBLE ANTEROLATERAL SUBENDOCARDIAL INJURY

67. MARKED ST ABNORMALITY, POSSIBLE INFEROLATERAL SUBENDOCARDIAL INJURY

68. MORE FREQUENT

69. (MASKED BY FASCICULAR BLOCK?)

70. MARKED T WAVE ABNORMALITY, CONSIDER ANTEROLATERAL ISCHEMIA

71. MARKED T WAVE ABNORMALITY, CONSIDER INFEROLATERAL ISCHEMIA

72. MARKED T WAVE ABNORMALITY, CONSIDER ANTERIOR ISCHEMIA

73. MARKED T WAVE ABNORMALITY, CONSIDER LATERAL ISCHEMIA

74. MARKED T WAVE ABNORMALITY, CONSIDER INFERIOR ISCHEMIA

75. NARROW QRS TACHYCARDIA

76. MANUAL READING REQUIRED DUE TO INCONSISTENT MORPHOLOGIES

77. MODERATE

78. MULTIFOCAL

79. SERIAL COMPARISON NOT PERFORMED, ALL PREVIOUS TRACINGS ARE OF POOR DATA QUALITY

80. IS (ARE) NO LONGER

81. (NO P-WAVES FOUND)

82. NORTHWEST AXIS

83. NEW

84. POOR DATA QUALITY IN CURRENT ECG PRECLUDES SERIAL COMPARISON

85. PREVIOUS ECG HAS UNDETERMINED RHYTHM, NEEDS REVIEW

86. THE PREMATURE CONTRACTIONS

87. ** ** ** * PEDIATRIC ECG ANALYSIS * ** ** **

88. PROMINENT MID-PRECORDIAL VOLTAGE

89. PR INTERVAL

90. PREMATURE SUPRAVENTRICULAR COMPLEXES

91. PREMATURE ECTOPIC COMPLEXES

92. , WITH POSTERIOR EXTENSION

93. POSTERIOR LEADS

94. QUESTIONABLE CHANGE IN ST SEGMENT

95. WITH QRS WIDENING AND REPOLARIZATION ABNORMALITY

96. QUESTIONABLE CHANGE IN T WAVES

97. QT HAS LENGTHENED

98. QT HAS SHORTENED

99. QRS DURATION

100. QRS VOLTAGE

101. QUESTIONABLE CHANGE IN

102. ABNORMAL QRS-T ANGLE, CONSIDER PRIMARY T WAVE ABNORMALITY

103. MINIMAL CRITERIA FOR LVH, MAY BE NORMAL VARIANT

104. WITH QRS WIDENING

105. QRS

106. DEEP Q-WAVE IN V6

107. ALTHOUGH RATE HAS INCREASED

108. ALTHOUGH RATE HAS DECREASED

109. LOW RIGHT ATRIAL BRADYCARDIA

110. LOW RIGHT ATRIAL TACHYCARDIA

111. EARLY REPOLARIZATON

112. ABNORMAL RIGHT SUPERIOR AXIS DEVIATION

113. RSR' OR QR PATTERN IN V1 SUGGESTS RIGHT VENTRICULAR
CONDUCTION DELAY

114. RHYTHM

115. LOW RIGHT ATRIAL RHYTHM

116. RARE

117. NONSPECIFIC CHANGE IN ST SEGMENT

118. WITH S-A BLOCK OR TRANSIENT A-V BLOCK

119. MARKED ST ABNORMALITY, POSSIBLE SEPTAL
SUBENDOCARDIAL INJURY

120. S1-S2-S3 PATTERN, CONSIDER PULMONARY DISEASE, RVH, OR
NORMAL VARIANT

121. SERIAL CHANGES OF

122. , MAY BE SECONDARY TO QRS ABNORMALITY

123. RSR' PATTERN IN V1

124. SIGNIFICANT CHANGES HAVE OCCURRED

125. SEPTAL INJURY PATTERN

126. SINUS RHYTHM

127. WITH SHORT PR

128. SEPTAL INFARCT

129. STATEMENT NOT FOUND

130. WITH SINUS ARREST TRANSIENT A-V BLOCK

131. SMALL

132. SEPTAL LEADS

133. T WAVES

134. T WAVE AMPLITUDE HAS INCREASED IN

135. T WAVE AMPLITUDE HAS DECREASED IN

136. SECOND DEGREE AV BLOCK, TYPE UNDETERMINED

137. TEACHING FILE

138. UNDETERMINED RHYTHM

139. VENT. RATE

140. VERY SMALL

141. VERY LARGE

142. ADVANCED SECOND DEGREE AV BLOCK

143. WITH RATE INCREASE

144. COMPLETE AV BLOCK

145. WITH RATE DECREASE

146. VENTRICULAR PRE-EXCITATION, WPW PATTERN TYPE A

147. VENTRICULAR PRE-EXCITATION, WPW PATTERN TYPE B

148. WITH 5:1 AV CONDUCTION

149. *** POOR DATA QUALITY, INTERPRETATION MAY BE ADVERSELY AFFECTED

150. LEFT ATRIAL RHYTHM

151. ACUTE PERICARDITIS

152. ELECTRONIC VENTRICULAR PACEMAKER

153. *** SUSPECT ARM LEAD REVERSAL, INTERPRETATION ASSUMES NO REVERSAL

154. RIGHTWARD AXIS

155. OTHERWISE NORMAL ECG

156. T WAVE ABNORMALITY, CONSIDER ANTERIOR ISCHEMIA

157. T WAVE ABNORMALITY, CONSIDER ANTEROLATERAL ISCHEMIA

158. T WAVE ABNORMALITY, CONSIDER INFERIOR ISCHEMIA

159. T WAVE ABNORMALITY, CONSIDER LATERAL ISCHEMIA

160. NONSPECIFIC INTRAVENTRICULAR CONDUCTION DELAY

161. WITH OCCASIONAL

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