

In summary, in addition to impaired feasibility problems of variability and reproducibility critically determine the potential of two-dimensional echocardiography in quantifying global and regional left ventricular function in man, this probably more than in angiocardiology; preliminary data suggest that errors in image recording and analyzing may preclude unreflected quantitation namely of wall motion abnormalities.

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The Role of Symbolic Processing in the Computer Evaluation of Left Ventricular Wall Motion: The ALVEN System

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Abstract

We propose that the current limited success of computer assisted analysis of left ventricular dynamics is due to three main reasons: 1) There is a strong tendency to remain within the realm of mathematical modelling for LV dynamics, and it is not all clear that this is an adequate approach: 2) In places where mathematical models alone may be insufficient, current computer science research into more sophisticated schemes is not yet complete, and thus, more "pure" computer science research is required, particularly into pattern recognition and artificial intelligence, before applications such as LV performance can be solved, a view also stated in Boehm and Hoehne (1981); 3) There is a distinct lack of knowledge about LV dynamics, in conjunction with disagreements about what is important to model and what terminology is to be used. We are addressing each of these issues in our research efforts, having at this point concentrated on the first two issues, as well as having designed a language for the expression of definitions for terminology, and implemented a prototype system for LV dynamics interpretation.

Introduction

The evaluation of left ventricular (LV) performance by computer from cine representations of LV dynamics is a difficult and long-studied problem. A large number of heuristics have been proposed for measuring shape changes (Brower and Meester 1981), following anatomical landmarks (Slager et al. 1981), computing segmental volume contributions (for a comparison, see Gelbert et al. 1979), etc., all performing with varying degrees of success, but being applied independently of each other. Although such heuristics are indeed valuable quantitative measures, we propose that their limited performance is due to two key considerations: 1) It is unlikely, given the complexity of the domain of LV dynamics and the amount of training that a clinical specialist in this area receives, that any single heuristic can capture all the important facets of the evaluation and be successful in all applications; 2) The heuristics are purely quantitative in nature, contrasting with the fact that clinicians, and for that matter humans in general, deal in qualitative or descriptive terms combined with numerical quantities. That is, relational quantities are necessary components of the interpretation process, while numerical ones are secondary. The key here is that a computer system that is to solve the difficult problems present in the domain of LV dynamics interpretation must integrate the above mentioned numerical heuristics as well as consider the symbolic processing aspects of the interpretation. We distinguish our approach from those whose goal is to provide some intermediate visual representation that must still be subjectively interpreted by a clinician, (the work described by Hoehne et al. 1980 is a particularly good example of such a representation). Our goal is to perform this interpretation, in much the same way as the clinician does, and to do it in an objective and consistent manner. We have designed the theoretical framework for a computer system that can perform such an integrative process, and have implemented it in a system called ALVEN. The premise used in the design is that if we wish to build a computer system that can perform at levels equal to expert human performance in some domain, then that computer system must contain the same knowledge employed by the human expert and must use the knowledge in much the same ways as the human expert does. The theoretical design and implementation is fully described by Tsotsos 1980 and 1981.

Briefly, the important concepts on which the computer system is based are as follows. We have designed and implemented a knowledge-based expert system for motion understanding that incorporates several novel features. A frame-based representation, which includes exception handling via similarity links and the organizational primitives IS-A (generalization/specialization) and PART-OF (part/whole) is used to construct a knowledge base of temporal concepts. A formal language has been designed that is used to create LV dynamics knowledge packages, (frames) and thus, since the knowledge is interpreted by the computer, these knowledge packages provide a set of formal definitions for our terminology. In addition, these definitions are easily examinable and modifiable by others. We believe that this will provide an approach to the solution of the terminology problem pointed out by Daughters et al. (1979); however, the problem of determining what the knowledge is, is still a major one. An iterative refinement solution is possible with this framework. This knowledge base drives the recognition process that integrates the paradigms of hypothesize-and-test and competition and co-operation among conceptually similar hypotheses. Image analysis is accomplished in a manner similar to that in Gerbrands et al. 1979.

LV Dynamics Knowledge and its Representation

Although there is still much work to be done in the determination of all the knowledge of LV dynamics, much can be found in current literature which can be incorporated into our formalism. Two examples will be given.

In the series of papers by Gibson and several investigations were carried out on motions. In the second paper quoted relaxation were examined in normal details of their method, we will briefly normal LVs an outward wall motion isovolumic relaxation. In abnormal c areas show inward motion, 2 mm of for anterior regions, and non-affected increased outward motion of up to 6 the description given does not have a quantitative and qualitative measures direction as long as the motion of the impossible to set up a mathematical cumbersome and will bury the pertinent non-sophisticated user becomes impos

The alternative is to devise a representation aspects. Let us look at the form of the ledge package in our scheme is called requisite components that provide parts that are computed from the prerequisite defined motion to other motions via be present. So, the definition of a non

frame N_ISOVOUMIC_RELAXAT

prerequisites

subj : N_LV;
anterior_mot : N_ANT_
[anterior_mot.subj
apical_mot : N_AP_ISO
[apical_mot.subj pa
posterior_mot : N_POST
[posterior_mot.subj

dependents

time_int : with
start_time ← anterior
[same(anterior_mot
apical_mot
posterior_
end time ← anterior
[same(anterior_mot
apical_mot
posterior_
duration default 0.1

similarity links

sim_link1 : ISCH_AP_IS

In the series of papers by Gibson and his colleagues (Doran et al. 1978; Gibson et al. 1976), several investigations were carried out that determined quantitative aspects of specific LV motions. In the second paper quoted, the segmental motions of the LV during isovolumic relaxation were examined in normal and ischemic LVs using echocardiography in order to determine dynamic differences between these two cases. Without describing technical details of their method, we will briefly summarize their findings. They discovered that in normal LVs an outward wall motion of 1.5–3.0 mm could be present in any region during isovolumic relaxation. In abnormal cases, i. e., patients with coronary artery disease, affected areas show inward motion, 2 mm or more for posterior or apical segments, and any at all for anterior regions, and non-affected areas, due to a compensatory mechanism, exhibit an increased outward motion of up to 6 mm over normal. The key feature to note here is that the description given does not have a mathematical form at all – it is a combination of quantitative and qualitative measures. The term “outwards” does not specify any precise direction as long as the motion of the segment is away from the inside of the LV. It is not impossible to set up a mathematical model of this; however, the model will be both cumbersome and will bury the pertinent facts in its equations, so that inspection by a non-sophisticated user becomes impossible.

The alternative is to devise a representational scheme that can incorporate both modelling aspects. Let us look at the form of the representation for the example cited above. A knowledge package in our scheme is called a *frame*. Each frame has a name, a number of prerequisite components that provide part of its definition, a number of dependent quantities that are computed from the prerequisites, and a number of similarity links that relate the defined motion to other motions via the set of possible differences, or anomalies that can be present. So, the definition of a normal isovolumic relaxation phase is partially given by:

frame N_ISOVOVIC_RELAXATION with

prerequisites

subj : N_LV;

anterior_mot : N_ANT_ISO_RELAX such that

[anterior_mot.subj. part_of self.subj];

apical_mot : N_AP_ISO_RELAX such that

[apical_mot.subj part_of self.subj];

posterior_mot : N_POST_ISO_RELAX such that

[posterior_mot.subj part_of self.subj]

dependents

time_int : with

start_time ← anterior_mot.time_int.start_time such that

[same(anterior_mot.time_int.start_time,
apical_mot.time_int.start_time,
posterior_mot.time_int.start_time)],

end_time ← anterior_mot.time_int.end_time such that

[same(anterior_mot.time_int.end_time,
apical_mot.time_int.end_time,
posterior_mot.time_int.end_time)],

duration default 0.12* AD/0.8

similarity links

sim_link1 : ISCH_AP_ISOVOL_RELAX

for differences:

- d1 : TOO_MUCH_MOTION where
[subj instance_of N_AP_SEG,
direction instance_of INWARDS
time_int = apical_mot.time_int];
- d2 : TOO_MUCH_MOTION where
[subj instance_of N_ANT_SEG,
direction instance_of OUTWARDS
time_int = anterior_mot.time_int];
- d3 : TOO_MUCH_MOTION where
[subj instance_of N_POST_SEG,
direction instance_of OUTWARDS,
time_int = posterior_mot.time_int];

sim_link2 : ISCH_ANT_ISOVOL_RELAX

for differences:

- d1 : TOO_MUCH_MOTION where
[subj instance_of N_ANT_SEG,
direction instance_of INWARDS,
time_int = anterior_mot.time_int];
- d2 : TOO_MUCH_MOTION where
[subj instance_of N_AP_SEG,
direction instance_of OUTWARDS,
time_int = apical_mot.time_int];
- d3 : TOO_MUCH_MOTION where
[subj instance_of N_POST_SEG,
direction instance_of OUTWARDS,
time_int = posterior_mot.time_int];

sim_link3 : ISCH_POST_ISOVOL_RELAX

for differences:

- d1 : TOO_MUCH_MOTION where
[subj instance_of N_POST_SEG;
direction instance_of INWARDS,
time_int = posterior_mot.time_int];
- d2 : TOO_MUCH_MOTION where
[subj instance_of N_ANT_SEG,
direction instance_of OUTWARDS,
time_int = anterior_mot.time_int];
- d3 : TOO_MUCH_MOTION where
[subj instance_of N_AP_SEG,
direction instance_of OUTWARDS,
time_int = apical_mot.time_int];

end

The definition states that for a normal isovolumic relaxation phase to be recognized, normal motions for each segment must be presented. The variable N_AP_ISO_RELAX refers to the frame that defines the motion of the apical segment during a normal isovolumic relaxation. The **prerequisite** portion specifies that there are three segments and that normal motions for each must be observed in order for the entire phase to be observed as normal. In addition, the **dependent** portion specifies timing information, such that each of the motions observed must occur simultaneously. Also, using the information derived

from Gibson et al. (1976), the similarity li must be found if a possible ischemic segme nections to possible ischemic states are inc would have to be present for other disease relaxation phase plays a role in their defini the motion of an abnormal apical segment to Gibson's definition, is shown by either t motion during this phase, and/or one of th too much outward motion during the phas define a necessary set; any one of the cond motion" is provided in the following frame motion (for example), that specifies the n

frame N_AP_ISO_RELAX with

prerequisites

subj : N_AP_SEG ;

mot : TRANSLATE such that

[(for dir1 : INWARDS w

[dir1 .subj = self.su

dir1 .ref = super_p

speed < 2 / time_i

or

for dir1 : OUTWARDS

[dir1 .subj = self.su

dir1 .ref = super_p

speed < 3 / time_i

exception TOO_MUCH

[subj ← self.subj,

direction ← dir1,

time_int ← self.tim

end

The frame for normal posterior motion for that for the anterior segment would differ i be replaced by one that specifies that no inv frame definitions to actual observed motion Exceptions are stored with sufficient inform for example) can determine which other fra manner. It should be clear that the above is definitions for the other phases and motion; motion is defined as a hierarchy of abstracti one. Some of the types of information that mal duration for each phase, modified by th cycle; volume changes where known for nor measures of degrees of abnormalities, derive operated upon as if it were a programming l implemented for this language).

A second body of knowledge of the form ne Fujii et al. (1979). These researchers investig clinical cardiac disease states with the intent ences and similarities among the diseases, as

from Gibson et al. (1976), the similarity links provide definitions of the constraints that must be found if a possible ischemic segment is to be recognized. Note that only the connections to possible ischemic states are included above; a set of similarly formed constraints would have to be present for other disease states as well, for those cases were the isovolumic relaxation phase plays a role in their definition. "sim_link1" relates the normal phase to the motion of an abnormal apical segment exhibiting the effects of ischemia. This, according to Gibson's definition, is shown by either the apical region itself having too much inward motion during this phase, and/or one of the other regions (posterior or anterior) exhibiting too much outward motion during the phase. Note that the set of differences does not define a necessary set; any one of the conditions is sufficient. The definition of "too much motion" is provided in the following frame, that is, the frame definition for normal apical motion (for example), that specifies the motion limits of the segment during this phase.

```

frame N_AP_ISO_RELAX with
  prerequisites
    subj : N_AP_SEG ;
    mot : TRANSLATE such that
      [(for dir1 : INWARDS where
        [dir1 .subj = self.subj,
         dir1 .ref = super_part(self).centroid,
         speed < 2 / time_int.duration]
       or
        for dir1 : OUTWARDS where
          [dir1 .subj = self.subj,
           dir1 .ref = super_part(self).centroid,
           speed < 3 / time_int.duration])
       exception TOO_MUCH_MOTION with
         [subj ← self.subj,
          direction ← dir1,
          time_int ← self.time_int]];
end

```

The frame for normal posterior motion for this phase would be virtually identical, while that for the anterior segment would differ in that the INWARDS motion constraint would be replaced by one that specifies that no inward motion should occur. In the matching of frame definitions to actual observed motions, matching failures are recorded as *exceptions*. Exceptions are stored with sufficient information so that the similarity links (sim_link1, for example) can determine which other frame definition to try in a hypothesize and test manner. It should be clear that the above is not complete; it requires the remainder of the definitions for the other phases and motions since the entire definition of each class of LV motion is defined as a hierarchy of abstraction, each level adding more detail to the previous one. Some of the types of information that are represented are: expected values of a normal duration for each phase, modified by the actual duration (AD) of the patient's heart cycle; volume changes where known for normal phases, ejection fractions, for example; measures of degrees of abnormalities, derived heuristically; and others. The above is operated upon as if it were a programming language (a compiler and interpreter have been implemented for this language).

A second body of knowledge of the form necessary for interpretation can be found in Fujii et al. (1979). These researchers investigated, again by echocardiography, 8 different clinical cardiac disease states with the intent of discovering posterior wall motion differences and similarities among the diseases, as well as global LV characteristics. The diseases

were: pericarditis, congestive cardiomyopathy, hypertrophic cardiomyopathy, valvular aortic stenosis, aortic insufficiency, mitral stenosis, mitral insufficiency, and systemic hypertension. Normal LV's were also studied. The measurements made for each of the above LV states were: stroke volume, rapid filling volume, slow filling volume, atrial filling volume, the percent filling for each of the previous three phases with respect to the stroke volume, posterior wall excursion in total, and for each of the 3 phases of diastole, as well as the percentage excursion in each phase, diastolic posterior wall velocity, rapid filling rate, LV end diastolic dimension, and ejection fraction. It is, of course, difficult to verify their results. However, they are important — it provides at least a starting point for the further elaboration and verification of such detailed dynamic information. In addition to the large amount of numerical information that they derived, they attached to the significant findings qualitative descriptors — such as whether or not a quantity should be higher or lower than in the normal case. This was rather fortunate from our point of view: the representational formalism that we had designed can handle description via common components and differences very well, and uses such information to advantage during the decision phases of the interpretation. Of course, a serious question does remain — how is this information related to that which can be derived from cine representations as opposed to echo representations. For this reason, we are using the numerical information as a starting point only and expect to iterate on it in order to converge to appropriate values. We do expect however, that the qualitative descriptors will not differ between imaging schemes. It should be clear from the previous example how such information would be included into the representation, and this fact alone raises another important advantage of this scheme. The addition of information into a mathematical model may require a complete re-definition of the model. In our case, information is easily inserted, as long as one understands the semantics of the language. It is therefore possible to include several different heuristics as mentioned before — however, their interactions then must be considered, and this is one research aspect that our group and no other group for that matter has considered.

Evaluation of Tantalum Marker Dynamics

The first domain of application of ALVEN is that of the evaluation of the dynamics of tantalum marker implants. The goal is to analyse both pre-operative (without markers, using contrast media) and post-operative marker films (following coronary bypass surgery), to evaluate the efficacy of surgery, locally and globally, quantitatively and qualitatively, over the recovery period (several months) and to evaluate the effects of drug interventions. The important phase of interpretation for the system is the discovery of differences between different sequences in time. For example, what improvement is there in posterior segmental contribution over time? Such analyses are possible within our framework since the interpretation process is expectation driven. On completing one sequence's interpretation, the result is used to create expectations for the next sequence, taken perhaps several weeks later, and deviations from it are noted. Other examples of computer analysis of marker implants are (Gerbrands et al. 1979), whose technique of marker identification is most similar to ours, and (Alderman et al. 1979) which addresses the problem of point of reference.

The initial evaluation is done on a cine contrast representation; each patient has a permanent volume correction factor both diastole and systole that accounts for the shell of muscle enclosed by the contour created by connecting the markers (Alderman et al. 1976). Interpolation is used for variations in this correction over time. Nine markers on the LV wall, and two on the aortic valve edges constitute the LV outline from which volume calculations are done, using an area-length formula that was devised for this purpose.

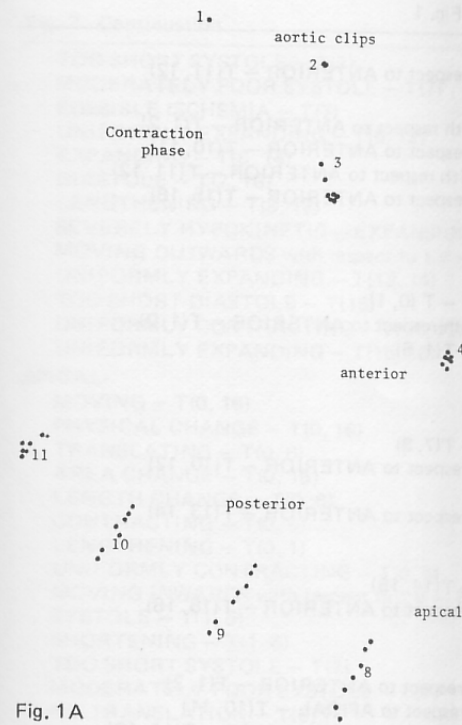


Fig. 1A

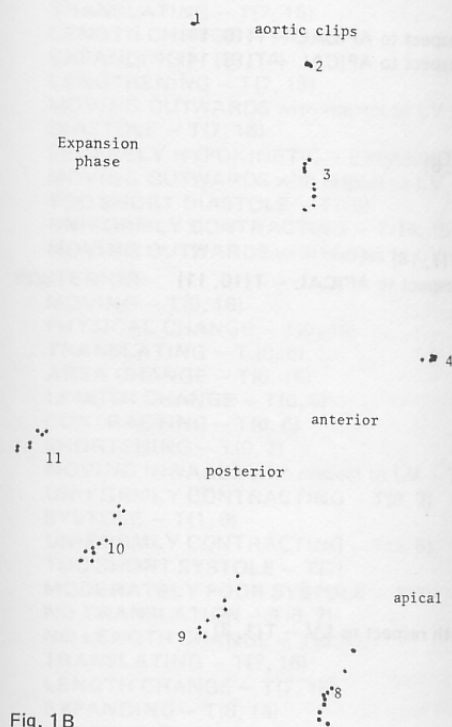


Fig. 1B

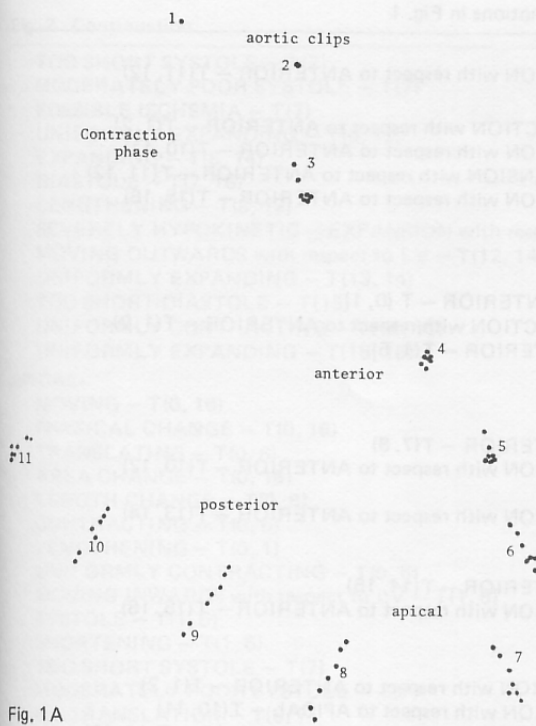


Fig. 1A

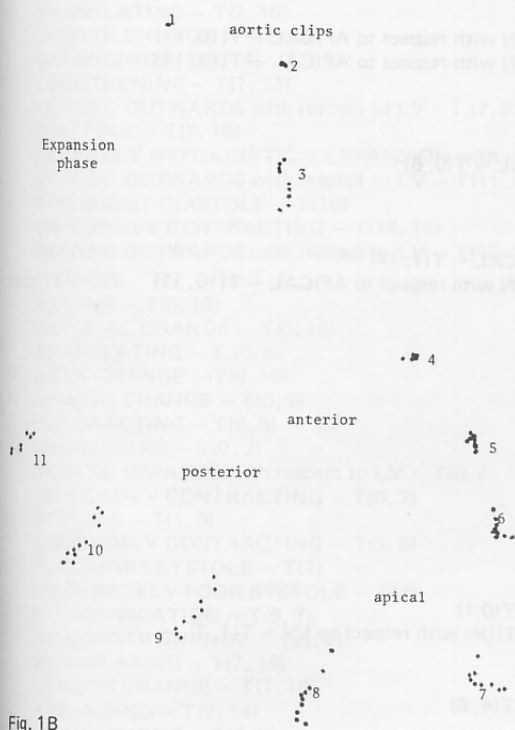


Fig. 1B

ALVEN is capable of reporting on LV performance at marker, segment and global levels of detail. Relative directions, motion extents, rates of change, and temporal relationships are described both numerically and symbolically. Anomalies are detected by using the appropriate heuristic or by comparisons to accepted normal performance. Anomalies such as asynchrony, hypokinesis, dyskinesis, too slow or fast rate of change of volume with respect to the LV phase, too long or short phase duration, or degree of anomaly are considered.

An example of marker motions is shown in Figs. 1A and 1B, for a patient from our unit. Fig. 1A shows the contraction phase, while Fig. 1B shows the expansion phase. This particular example was assessed by the radiologists with respect to motion anomalies: the radiologist reported that the anterior segment was hypokinetic, and the remaining segments exhibited normal motion. A portion of the output of the ALVEN system for this particular film (taken at 30 images/second, 17 images in all) is shown in Fig. 2. Let us highlight some of the important points of this analysis. Firstly, a short summary of how to read the example is necessary. For each physical entity that the system knows about, that is in this case, the markers, the segments and the LV as a whole, a short summary of the motions observed is produced. This has been abbreviated due to space limitations in the following way: descriptions for the aortic clips were deleted, the descriptions for markers 3, 4, 6, 7, 9, 10, 11, were modified so that only abnormalities that were detected are shown — the remaining motions would have a form similar to these for the other markers. Each motion has a descriptive term, a possible referent where necessary (for example,

Fig. 2 ALVEN's descriptive output for the motions in Fig. 1

marker 3:
SEVERELY HYPOKINETIC — EXPANSION with respect to ANTERIOR — T(11, 12)

marker 4:
SEVERELY HYPOKINETIC — CONTRACTION with respect to ANTERIOR — T(1, 2)
SEVERELY HYPOKINETIC — EXPANSION with respect to ANTERIOR — T(10, 11)
MODERATELY HYPOKINETIC — EXPANSION with respect to ANTERIOR — T(11, 12)
SEVERELY HYPOKINETIC — EXPANSION with respect to ANTERIOR — T(15, 16)

marker 5:
MOVING — T(0, 5)
TRANSLATING — T(0, 5)
MOVING OUTWARDS with respect to ANTERIOR — T(0, 1)
SEVERELY HYPOKINETIC — CONTRACTION with respect to ANTERIOR — T(1, 2)
MOVING INWARDS with respect to ANTERIOR — T(1, 5)
NO MOTION — T(5, 6)
MOVING — T(6, 10)
TRANSLATING — T(6, 10)
MOVING INWARDS with respect to ANTERIOR — T(7, 8)
SEVERELY HYPOKINETIC — EXPANSION with respect to ANTERIOR — T(10, 12)
NO MOTION — T(10, 14)
SEVERELY HYPOKINETIC — EXPANSION with respect to ANTERIOR — T(13, 14)
MOVING — T(14, 15)
TRANSLATING — T(14, 15)
MOVING INWARDS with respect to ANTERIOR — T(14, 15)
SEVERELY HYPOKINETIC — EXPANSION with respect to ANTERIOR — T(15, 16)
NO MOTION — T(15, 16)

marker 6:
MILDLY HYPOKINETIC — CONTRACTION with respect to ANTERIOR — T(1, 2)
SEVERELY HYPOKINETIC — EXPANSION with respect to APICAL — T(10, 11)
MODERATELY HYPOKINETIC — EXPANSION with respect to ANTERIOR — T(11, 12)
SEVERELY HYPOKINETIC — EXPANSION with respect to APICAL — T(12, 13)

marker 7:
SEVERELY HYPOKINETIC — EXPANSION with respect to APICAL — T(10, 11)
SEVERELY HYPOKINETIC — EXPANSION with respect to APICAL — T(13, 14)

marker 8:
MOVING — T(0, 6)
TRANSLATING — T(0, 6)
MOVING INWARDS with respect to APICAL — T(0, 6)
NO MOTION — T(6, 7)
MOVING — T(7, 15)
TRANSLATING — T(7, 15)
MOVING OUTWARDS with respect to APICAL — T(7, 14)
SEVERELY HYPOKINETIC — EXPANSION with respect to APICAL — T(10, 11)
NO MOTION — T(15, 16)

marker 9:
marker 10:
marker 11:
ANTERIOR:
MOVING — T(0, 16)
PHYSICAL CHANGE — T(0, 16)
TRANSLATING — T(0, 16)
AREA CHANGE — T(0, 16)
LENGTH CHANGE — T(0, 16)
CONTRACTING — T(0, 6)
SHORTENING — T(0, 2)
MOVING INWARDS with respect to LV — T(0, 1)
SEVERELY HYPOKINETIC — CONTRACTION with respect to LV — T(1, 3)
UNIFORMLY CONTRACTING — T(1, 5)
SYSTOLE — T(1, 6)
MOVING INWARDS with respect to LV — T(4, 6)

Fig. 2 Continuation

TOO SHORT SYSTOLE — T(7)
MODERATELY POOR SYSTOLE — T(7)
POSSIBLE ISCHEMIA — T(7)
UNIFORMLY EXPANDING — T(6, 12)
EXPANDING — T(6, 14)
DIASTOLE — T(7, 16)
LENGTHENING — T(8, 12)
SEVERELY HYPOKINETIC — EXPANSION
MOVING OUTWARDS with respect to LV —
UNIFORMLY EXPANDING — T(13, 14)
TOO SHORT DIASTOLE — T(15)
UNIFORMLY CONTRACTING — T(14, 15)
UNIFORMLY EXPANDING — T(15, 16)

APICAL:
MOVING — T(0, 16)
PHYSICAL CHANGE — T(0, 16)
TRANSLATING — T(0, 6)
AREA CHANGE — T(0, 16)
LENGTH CHANGE — T(0, 6)
CONTRACTING — T(0, 6)
LENGTHENING — T(0, 1)
UNIFORMLY CONTRACTING — T(0, 6)
MOVING INWARDS with respect to LV — T
SYSTOLE — T(1, 6)
SHORTENING — T(1, 6)
TOO SHORT SYSTOLE — T(7)
MODERATELY POOR SYSTOLE — T(7)
NO TRANSLATION — T(6, 7)
NO LENGTH CHANGE — T(6, 7)
UNIFORMLY EXPANDING — T(6, 13)
TRANSLATING — T(7, 16)
LENGTH CHANGE — T(7, 16)
EXPANDING — T(6, 14)
LENGTHENING — T(7, 13)
MOVING OUTWARDS with respect to LV —
DIASTOLE — T(7, 16)
SEVERELY HYPOKINETIC — EXPANSION
MOVING OUTWARDS with respect to LV —
TOO SHORT DIASTOLE — T(15)
UNIFORMLY CONTRACTING — T(14, 15)
MOVING OUTWARDS with respect to LV —

POSTERIOR:
MOVING — T(0, 16)
PHYSICAL CHANGE — T(0, 16)
TRANSLATING — T(0, 6)
AREA CHANGE — T(0, 16)
LENGTH CHANGE — T(0, 6)
CONTRACTING — T(0, 6)
SHORTENING — T(0, 2)
MOVING INWARDS with respect to LV — T
UNIFORMLY CONTRACTING — T(0, 2)
SYSTOLE — T(1, 6)
UNIFORMLY CONTRACTING — T(3, 6)
TOO SHORT SYSTOLE — T(7)
MODERATELY POOR SYSTOLE — T(7)
NO TRANSLATION — T(6, 7)
NO LENGTH CHANGE — T(6, 7)
TRANSLATING — T(7, 16)
LENGTH CHANGE — T(7, 16)
EXPANDING — T(6, 14)
LENGTHENING — T(7, 8)

Fig. 2 Continuation

TOO SHORT SYSTOLE – T(7)
 MODERATELY POOR SYSTOLE – T(7)
 POSSIBLE ISCHEMIA – T(7)
 UNIFORMLY EXPANDING – T(6, 12)
 EXPANDING – T(6, 14)
 DIASTOLE – T(7, 16)
 LENGTHENING – T(8, 12)
 SEVERELY HYPOKINETIC – EXPANSION with respect to LV – T(11, 12)
 MOVING OUTWARDS with respect to LV – T(12, 14)
 UNIFORMLY EXPANDING – T(13, 14)
 TOO SHORT DIASTOLE – T(15)
 UNIFORMLY CONTRACTING – T(14, 15)
 UNIFORMLY EXPANDING – T(15, 16)

APICAL:

MOVING – T(0, 16)
 PHYSICAL CHANGE – T(0, 16)
 TRANSLATING – T(0, 6)
 AREA CHANGE – T(0, 16)
 LENGTH CHANGE – T(0, 6)
 CONTRACTING – T(0, 6)
 LENGTHENING – T(0, 1)
 UNIFORMLY CONTRACTING – T(0, 6)
 MOVING INWARDS with respect to LV – T(1, 6)
 SYSTOLE – T(1, 6)
 SHORTENING – T(1, 6)
 TOO SHORT SYSTOLE – T(7)
 MODERATELY POOR SYSTOLE – T(7)
 NO TRANSLATION – T(6, 7)
 NO LENGTH CHANGE – T(6, 7)
 UNIFORMLY EXPANDING – T(6, 13)
 TRANSLATING – T(7, 16)
 LENGTH CHANGE – T(7, 16)
 EXPANDING – T(6, 14)
 LENGTHENING – T(7, 13)
 MOVING OUTWARDS with respect to LV – T(7, 9)
 DIASTOLE – T(7, 16)
 SEVERELY HYPOKINETIC – EXPANSION with respect to LV – T(10, 11)
 MOVING OUTWARDS with respect to LV – T(11, 14)
 TOO SHORT DIASTOLE – T(15)
 UNIFORMLY CONTRACTING – T(14, 15)
 MOVING OUTWARDS with respect to LV – T(15, 16)

POSTERIOR:

MOVING – T(0, 16)
 PHYSICAL CHANGE – T(0, 16)
 TRANSLATING – T(0, 6)
 AREA CHANGE – T(0, 16)
 LENGTH CHANGE – T(0, 6)
 CONTRACTING – T(0, 6)
 SHORTENING – T(0, 2)
 MOVING INWARDS with respect to LV – T(0, 6)
 UNIFORMLY CONTRACTING – T(0, 2)
 SYSTOLE – T(1, 6)
 UNIFORMLY CONTRACTING – T(3, 6)
 TOO SHORT SYSTOLE – T(7)
 MODERATELY POOR SYSTOLE – T(7)
 NO TRANSLATION – T(6, 7)
 NO LENGTH CHANGE – T(6, 7)
 TRANSLATING – T(7, 16)
 LENGTH CHANGE – T(7, 16)
 EXPANDING – T(6, 14)
 LENGTHENING – T(7, 8)

Fig. 2 Continuation

UNIFORMLY EXPANDING – T(6, 14)
 DIASTOLE – T(7, 16)
 MOVING OUTWARDS with respect to LV – T(8, 13)
 LENGTHENING – T(9, 13)
 TOO SHORT DIASTOLE – T(15)
 MOVING INWARDS with respect to LV – T(13, 15)
 UNIFORMLY CONTRACTING – T(14, 15)

LV:

MOVING – T(0, 16)
 ISOMETRIC CONTRACTION – T(0, 1)
 PHYSICAL CHANGE – T(0, 16)
 TRANSLATING – T(0, 16)
 AREA CHANGE – T(0, 16)
 LENGTH CHANGE – T(0, 16)
 CONTRACTING – T(0, 6)
 SHORTENING – T(0, 6)
 UNIFORMLY CONTRACTING – T(0, 6)
 SYSTOLE – T(1, 6)
 TOO SHORT SYSTOLE – T(7)
 MODERATELY POOR SYSTOLE – T(7)
 ISOMETRIC RELAXATION – T(6, 7)
 UNIFORMLY EXPANDING – T(6, 14)
 EXPANSION ASYNCHRONY – T(7)
 EXPANDING – T(6, 14)
 LENGTHENING – T(6, 16)
 DIASTOLE – T(7, 16)
 MODERATELY DYSKINETIC – EXPANSION – T(9, 10)
 MODERATELY DYSKINETIC – EXPANSION – T(13, 14)
 TOO SHORT DIASTOLE – T(15)
 UNIFORMLY EXPANDING – T(15, 16)

“INWARD” motion is not semantically complete without saying inwards with respect to some other object that has an inside, usually defined by the geometric centroid), and a time interval or instant at which it was recognized. The “T(–,–)” notation gives the time interval while “T(–)” gives a time instant. Time is noted in image units. The range of descriptive terms that ALVEN can understand is apparent from the example.

Secondly, the example of the knowledge for isovolumic relaxation given earlier is useful for this example. The motions exhibited by the anterior segment, that is, there is a small outward motion during that phase, cause that chunk of knowledge to be activated and verified. The result is the descriptive term “POSSIBLE ISCHEMIA” which can be found in the description of the motions of the anterior segment. In addition, it will usually be true that if one segment is not performing up to par, (notice that of the number of HYPOKINESIS instances detected the great majority are present for the anterior segment thus confirming the radiologist’s report), then the overall performance of ventricle must be impaired as well. This can be seen by the instances of “POOR SYSTOLE” that appear. These are confirmed independently using volume change information.

Some other interesting descriptive terms are briefly described. UNIFORM CONTRACT/EXPAND – for this to be detected, the object considered must have a decreasing volume, and all of its markers/segments (depending on the level of description) must be moving in the proper direction. So for a uniform contraction at the LV level, the 3 segments must all be moving inwards and the overall volume of the LV must be decreasing. HYPOKINESIS – can only be noted if all markers/segments are moving in the same direction, and a comparison of their relative motions reveals one that is lagging behind. Note that the use of the

term hypokinesis does not make sense if since this is a term describing anomalies of slowly, then no anomaly is detected at that level. If in turn, all segments are exhibiting at all, however, serious performance problem will be lower than normal. The detection that it is not necessarily so. The data in (1) information on normal and abnormal extent incorporated into the representation. However, lacking information.

No constraints are currently in place for circumferential shortening, although exam

Conclusions

Current computer assisted analysis of LV pattern recognition and artificial intelligence dynamics knowledge, showing that knowledge of qualitative and quantitative facts, on relational attributes than on numerical basic computer science techniques necessary performance.

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term hypokinesis does not make sense if all markers are not moving in the same direction, since this is a term describing anomalies of motion extent. If they are all moving too slowly, then no anomaly is detected at the marker level but it is detected at the segment level. If in turn, all segments are exhibiting small motion extents, no hypokinesis is noted at all, however, serious performance problems will be noted, because the volume changes will be lower than normal. The detection of hypokinesis is purely relational. Note however, that it is not necessarily so. The data in (Fujii et al. 1979) do provide some quantitative information on normal and abnormal extents for the posterior segment; these will be incorporated into the representation. However, the relational approach is a valid one when lacking information.

No constraints are currently in place for length changes — that is, normal or abnormal circumferential shortening, although examples are shown of how such changes are detected.

Conclusions

Current computer assisted analysis of LV performance is limited by the state of the art in pattern recognition and artificial intelligence. This was motivated with examples of LV dynamics knowledge, showing that knowledge is not mathematical in nature but is a mixture of qualitative and quantitative facts, and that interpretation places stronger emphasis on relational attributes than on numerical ones. Our research is providing some of the basic computer science techniques necessary for such integrative interpretation of LV performance.

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