Body Surface Mapping After Partial Left Ventriculotomy

(#2001-35440)

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ABSTRACT

Objective: To demonstrate cardiac electrophysiological changes in patients where partial left ventriculotomy was performed and multichannel electrocardiographical measurements and body surface potential mapping were used.

Methods: Body surface ECG signals were recorded during sinus rhythm for one minute. Six patients were operated on with partial left ventriculotomy were monitored. All patients had normal coronary angiography data. The data were acquired prior to the partial left ventriculotomy, and on the second, third, fourth, and fifth postoperative day using 32-body surface leads. The recorded data were analysed by determining ST-40 and QRS integral maps. The analysis was done on a set of selected beats during the sinus rhythm and on the averaged beats.

Results: Before the operation, ST-40 maps typically showed an area of strong positive potentials (elevation) over the anterior aspect of the torso and a region of strong negative potentials (depression) over the lateral, and posterior aspects of the torso. After the operation, the ST elevation over the anterior, lateral and posterior aspects of the torso was reduced. An area of marked positive potentials remained in the precordial area (overlying the excised area of the heart), even during the postoperative monitoring interval (day two through day five). We also noticed that the amplitude of cardiac signals decreased by approximately 30% after the partial left ventriculotomy. Qualitative map changes were substantiated by statistical parameters.

Conclusions: Results of our study demonstrate that non-invasive acquisition of body-surface electrocardiographs may detect changes in the cardiac activity of patients undergoing partial left ventriculotomy. This finding suggests that body surface mapping may also be useful in assessing the arrhythmia vulnerability.

Presented at the International Symposiums on Beating Heart Surgery, Belo Horizonte, Brazil, 1999-2001.

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INTRODUCTION

During the last decade, partial left ventriculotomy (PLV) was thought to be a promising method of treating terminal-phase cardiac patients. Until now, more than 1,000 patients were operated on worldwide using this technique. It appears that a firm basis of diagnostic, preoperative, intraoperative, and postoperative measurements and evaluation has still not been established. One of the major complications following the operation is the frequent occurrence of sudden cardiac death. It appears that ventricular tachyarrhythmias are probable causes of these fatal events although it is not clear to what extent. It would thus be of interest to more closely study the susceptibility of patients who undergo PLV to such arrhythmias.

Body surface potential mapping (BSPM) involves the simultaneous recording of multiple ECG leads over the entire thorax. It displays the data as isopotential maps on a planar projection of a thoracic surface. Since BSPM collects data over the entire torso, it markedly expands diagnostic capabilities of standard 12-lead electrocardiography. Among its many applications, BSPM has been used to identify both depolarization and repolarization properties of the ventricles. Since BSPM provides spatial and temporal information about the cardiac electrical activity, it has been referred to as non-invasive electrophysiological imaging [Lux 1993].

In the present study, we sought to determine the changes in multiple body surface potentials in patients who underwent PLV. In particular, we attempted to monitor these changes within the first week following the operation. Our study represents an initial step in the non-invasive diagnosis of PLV patients, with the final goal to assess their susceptibility to ventricular arrhythmias.

MATERIAL AND METHODS

Patients

We performed BSPM during sinus rhythm in six patients (Table 1,). These patients, whose mean age was 52 ± 4.8 (range 44-57) years, were selected because they were scheduled to undergo PLV due to dilative cardiomyopathy. None of the patients had concomitant coronary artery disease and all patients were treated with 200 mg amiodarone daily preoperatively.

All patients were operated at the Hospital Angelina Caron, following the procedure described previously [Batista 1996].

Table 1. Preoperative data of patients operated for Partial Left Ventriculotomy.

ID	AGE [years]	SEX	EF-E [%]	QRS [ms]
5-F	53	m	24	107
5-G	56	f	30	171
5-B	44	m	25	219
5-I	53	m	33	152
5-E	57	m	42	141
5-A	49	m	37	130

ID = patient ID and also a part of measurement name, m = male, f = female, EF-E = Echo Ejection Fraction, QRS = duration in ms.

Immediately after the operation, patients were transferred to the Intensive Care Unit, where they stayed until the third or fourth postoperative day. The Institutional Review Board of Hospital Angelina Caron approved the study's protocol and all patients provided written consent before participating.

Body surface potential mapping

In all patients, BSPM (3 – 5) was performed one day prior to the operation, and on the second, third, fourth, and fifth day after surgery. For each patient, 32-lead electrocardiograms were simultaneously recorded for 60 seconds at a sampling rate of 1,000 Hz (with 14-bit amplitude resolution) using the recording system developed in our laboratory [Avbilj 1997]. Analog RC type high-pass and low-pass filtering was applied to ECGs at 0.05 and 150 Hz, respectively. The mean rms-value of the total baseline noise including mio-electric activity ± SD was 12.14 ± 7.123 µV with minimal and maximal values of 4.65 µV and 30.3 µV, respectively. The ECG signals were processed off-line and averaged over five cardiac cycles.

For visualization, multiple ECGs were displayed as isofield contour lines at each time instant. The beginning and the end of the QRS complex (the J point) were determined by visually inspecting ECG signals from all leads. The QRS integral maps were calculated for each lead as an algebraic sum of all ECG values from the onset to the offset of the QRS complex, multiplied by the interval length. The ST-40 maps represent an average potential on each lead from the J-point to 40-ms after this point.

To quantitatively assess the variability of maps prior and after the procedure, we used correlation coefficient CC_{xy} and root-mean square RMS_{xy} defined as

$$CC_{xy} = \frac{\sum_{i=1}^{N}(x_i - X)(y_i - Y)}{\sqrt{\sum_{i=1}^{N}(x_i - X)^2 \sum_{i=1}^{N}(y_i - Y)^2}},$$

$$RMS_{xy} = \frac{\sqrt{\sum_{i=1}^{N}(x_i - y_i)^2}}{\sqrt{N}},$$

where N denotes the number of channels (35 in our study), X and Y the means and x_i and y_i corresponding map values for the first and second map, respectively.

RESULTS

For each patient, we examined ST-40 and QRS integral maps, and calculated corresponding statistical parameters (CC and RMS). Typical sets of ST-40 and QRS integral maps, derived from the measurements on patient 5-I, are shown in Figure 1 and Figure 2 ( ), respectively.

Figure 1( ) shows changes in the distribution of ST-40 maps before and after the PLV for the representative patient (5-I). In this patient, the ST-40 map prior to the PLV (Figure 1a,) exhibits an area of strong positive potentials which covers the right anterior torso; the maximum is positioned near the precordial lead V1. The region of negative potentials covers the left anterior torso, with the minimum located in the upper anterior torso. Following the PLV, i.e., on the second day after the operation (Figure 1b,), the area of positive potentials shifts to the left, covering nearly the entire anterior torso; the potential maximum is between the precordial leads V2 and V3. The amplitudes of negative potentials are markedly lower than prior to the operation, with the minimum located in the shoulder area of the posterior torso. Some small changes in potential distribution can be seen on the third day after the operation where the minimum shifts toward the neck area of the anterior torso. This pattern remained relatively stable on the fourth and fifth days after the operation.

Figure 2 ( ) shows QRS isointegral maps for the same patient (5-I). Prior to the PLV (Figure 2a,), the distribution features strong negative potentials over the right anterior torso, with the minimum near the precordial lead V1. The region of positive potentials is in the upper left anterior torso. After the operation (Figures 2b through 2e,), the amplitude of QRS integrals is markedly diminished. The location of minimum shifts toward the precordial lead V1, while the maximum is located in the shoulder area of the anterior torso. Again, the pattern remained stable from the second day after the operation onwards.

To quantitatively assess the differences in maps before and after the operation, we used the correlation coefficient and rms value. Figures 3 and 4 ( ) summarize the results for all patients.

In five out of six patients, the correlation between the ST-40 distribution prior to the operation and the second postoperative day resulted in values in the range of -0.6 to 0.8 (Figure 3a,). After the operation, the pattern remained stable with the correlations above 0.85. In one patient (5-A), no marked changes in ST-40 distributions could be observed.

The comparison between preoperative measurements and the earliest postoperative measurement reveals that the ST-40 maps underwent a marked change soon after the surgery and then stabilized, remaining relatively unaltered between day 2 and day 5. It appears that these changes in the ST-40 maps reflect changes in cardiac electrical activity due to the PLV.

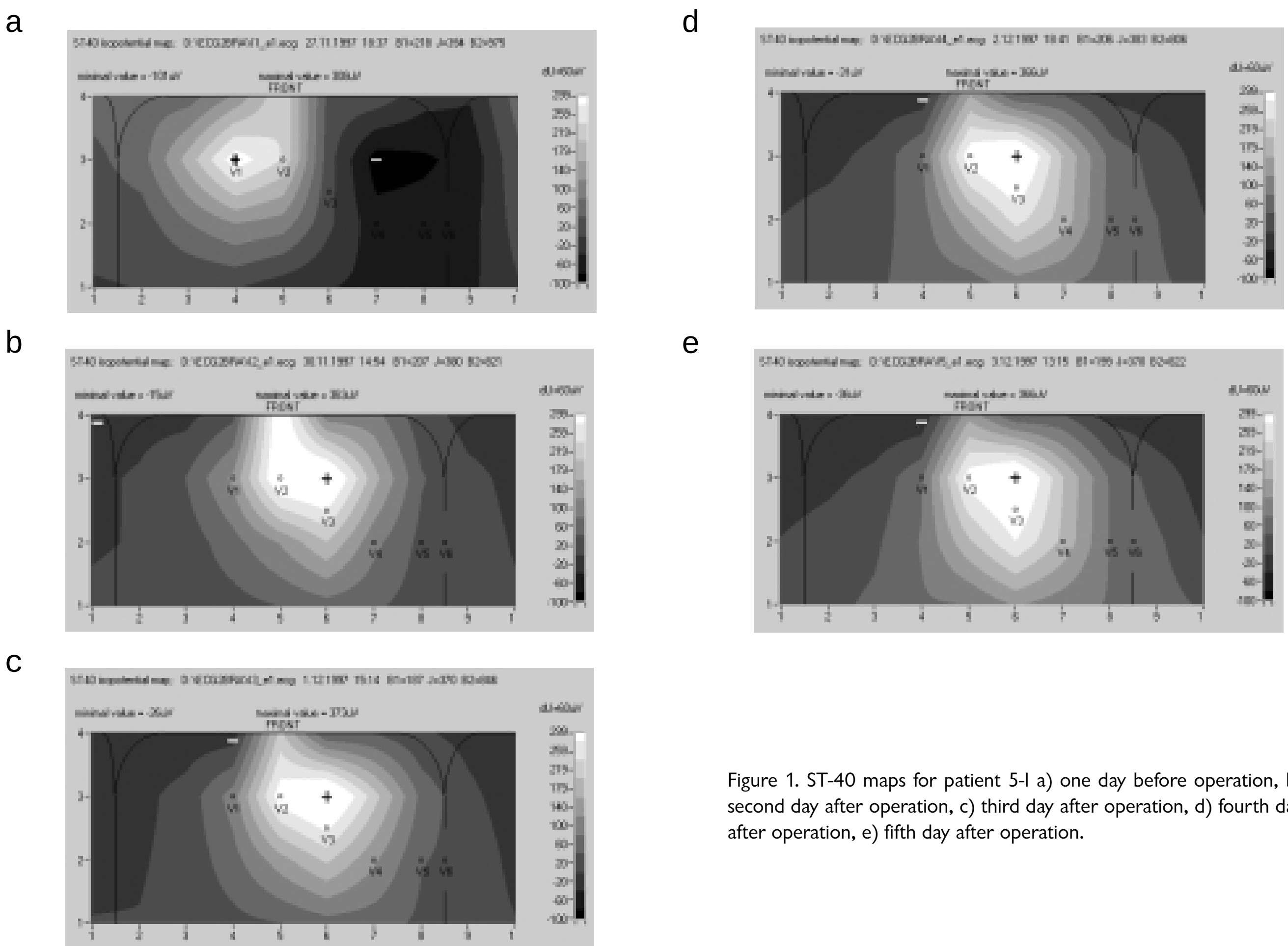

Figure 1. ST-40 maps for patient 5-I a) one day before operation, b) second day after operation, c) third day after operation, d) fourth day after operation, e) fifth day after operation.

The lower part in Figure 3 ( ) represents the actual differences in signals on all electrodes. From the trends in particular graphs, we can follow the evolution and differences between the preoperative state and consecutive postoperative days (Figure 3a,) and between the first postoperative day and three consecutive postoperative days (Figure 3b,). Trends similar to those above could be observed. We can see from the lower part of Figure 3b ( ) that the differences between consecutive days RMS_{24} - RMS_{23}, RMS_{25} - RMS_{24} became progressively smaller, which again indicates the stabilization of the map pattern.

Although trends similar to those in the ST-40 maps could be observed in the QRS integral maps, it appears that these changes were less pronounced. Figure 4a ( ) shows the changes in the QRS integral maps in the second day period after surgery. It is important to note that the scale is different than in Figure 3 ( ). After the second day, the maps stabilize and converge to new stable states (see CC_{03}, CC_{04}, CC_{05}). The exceptions are patients 5-I and 5-A, where some oscillation in the correlation coefficient can be observed. These new states are addressed again in column b. In general, for a given patient the differences between post surgical days are minimal.

Average Body Surface Potential

Average Body Surface Potential for all measurements and for all patients shows decreased values after the operation. The average was calculated from a selected R-R beat from all samples and all channels.

We followed up on patients up to 3 years postoperatively, and four out of six enjoyed normal lives. One patient died while working (patient A) five months after the operation, while for one patient (patient G) we were unable to collect postoperative data.

DISCUSSION

Our study is the first to examine changes in the multiple ECGs recorded over the entire thorax of patients who underwent PLV. The results suggest that multiple body surface ECGs have high spatial resolution and are sensitive to focal or regional non-homogeneous ventricular depolarization and repolarization [Abildskov 1987, Sippens-Groenewegen 1998, Green 1994, Hubley-Kozey 1995, Hren 1999]. Several clinical studies have indicated that body surface ECGs can be used for detecting patients who are at risk for ventricular arrhythmias [Green 1994, Gersak 1997, Trobec 1998]. Our

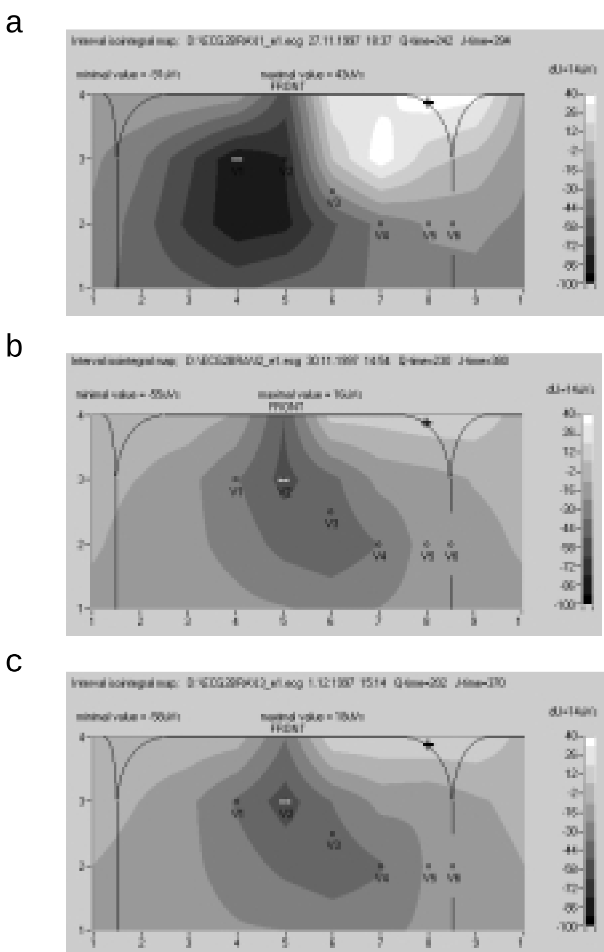
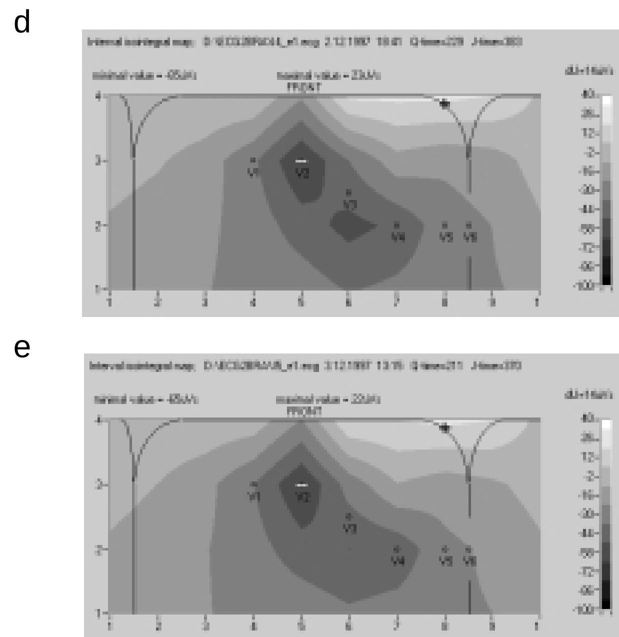

Figure 2. QRS integral maps for patient 5-I a) one day before operation, b) second day after operation, c) third day after operation, d) fourth day after operation, e) fifth day after operation.

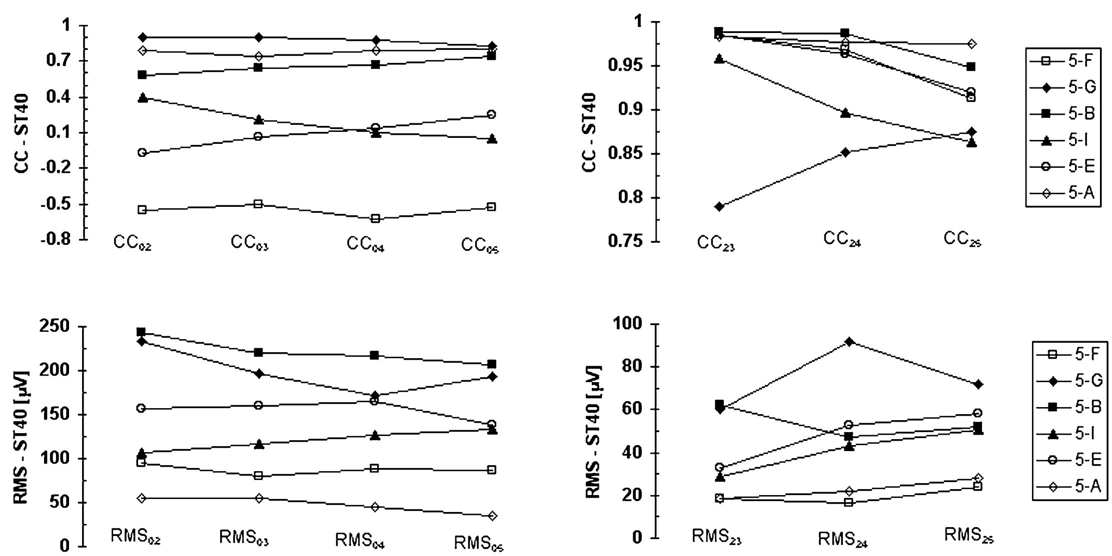

Figure 3. CC (upper graphs) and RMS (lower graphs) for ST-40 maps for all patients. Comparisons with the preoperative measurement - left column a) and comparisons with the earliest postoperative measurement (second day after surgery) - right column b). Index 0 denotes the measurement taken before operation, indices 2,3,4,5 mean the second, third, fourth and fifth day after operation, respectively.

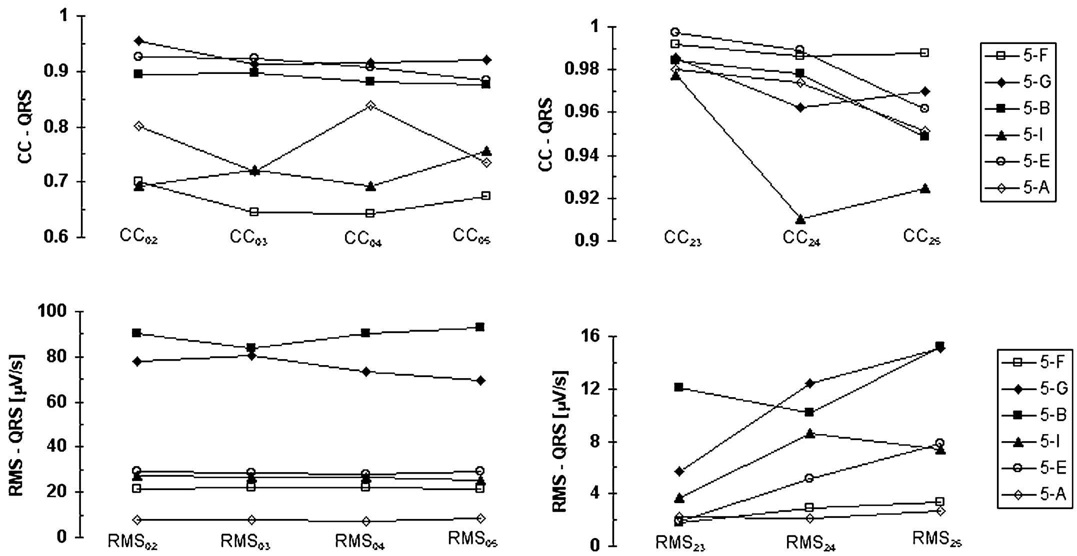

Figure 4. CC (upper graphs) and RMS (lower graphs) for QRS integral maps for all patients. Comparisons with the preoperative measurement - left column a) and comparisons with the earliest postoperative measurement (second day after surgery) - right column b). Index 0 denotes the measurement taken before operation, indices 2,3,4,5 mean the second, third, fourth and fifth day after operation, respectively.

study could thus be extended to a larger group of patients using quantitative means to assess features of integral maps [Hubley-Kozey 1995].

In all patients, changes in the ST-40 maps related spatially to the PLV procedure. Before the operation, maps of the candidates for PLV revealed the same pattern – an area of positive potentials (ST elevation) over the anterior aspect of the torso and a region of negative potentials (ST depression) over the lateral and posterior aspects of the torso. It should be noted that all of these patients had normal coronary angiography data. After the operation, the ST maps showed a substantial reduction of ST elevation over the anterior, lateral and posterior aspects of the torso, with an area of strong positive potentials remaining in the precordial area. This area is typically circumferential on the ST map and shows a decrease of ST elevation from the second to the fifth postoperative day. We hypothesize that this area reflects the excision and the suture line. Namely, the excision goes down from the junction between the middle and distal third of the LAD artery, between the anterior and posterior papillary muscle toward the mitral valve and the base of the heart.

From the changes in the ST segment, it can be seen that the region around the excised area could become arrhythmogenic after PLV. The changes in the duration of the Q-T interval after PLV, as obtained with our method, have shown delays up to 450 milliseconds in this region in some patients, giving the possibility for the re-entry mechanism after PLV.

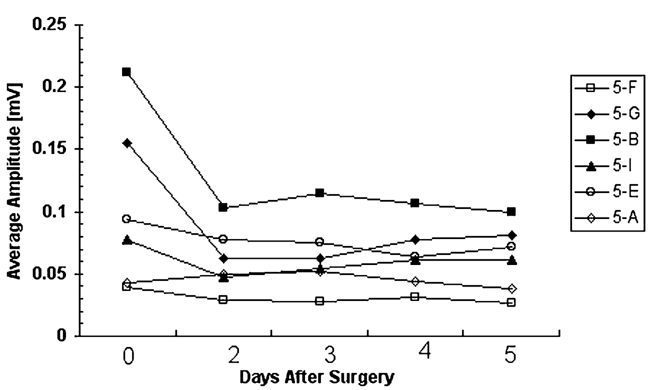

Figure 5. Average Body Surface Potential for all measurements and for all patients. The average was calculated from a selected R-R beat for all samples from all channels. Numbers on the X-axis denote: 0 - the measurement taken before operation; 2,3,4,5 – the second, third, fourth and fifth day after operation, respectively.

ACKNOWLEDGMENT

The authors would like to acknowledge the staff of the hospital Angelina Caron for their kind co-operation and support. We also wish to thank Ivan Knezevic, MD and Viktor Avbelj, MSc for their teamwork in BSPM measurements. This research was supported in part by the Jozef Stefan Institute, the Slovenian Ministry of Research and Technology, and the Ljubljana University Medical Center.

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