Prehospital 12-Lead ECG to Triage ST-Elevation Myocardial Infarction and Emergency Department Activation of the Infarct Team Significantly Improves Door-to-Balloon Times

Ambulance Victoria and MonashHEART Acute Myocardial Infarction (MonAMI) 12-Lead ECG Project

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Background—American College of Cardiology/American Heart Association guidelines recommend >75% of patients with an ST-elevation myocardial infarction receive primary percutaneous coronary interventions (PPCI) within 90 minutes. Despite these recommendations, this goal has been difficult to achieve.

Methods and Results—We conducted a prospective interventional study involving 349 patients undergoing PPCI at a single tertiary referral institution to determine the impact of prehospital 12-lead ECG triage and emergency department activation of the infarct team on door-to-balloon time (D2BT). The median D2BT of all patients (n = 107) who underwent PPCI after field ECG and emergency department activation of the infarct team (MonashHEART Acute Myocardial Infarction [MonAMI] group) was 56 minutes (interquartile range, 36.5 to 70) compared with the median time of a contemporary group (n = 122) undergoing PPCI during the same period but not receiving field triage (non-MonAMI group) of 98 minutes (73 to 126.45). The median D2BT time of 120 consecutive patients who underwent PPCI before initiation of the project (pre-MonAMI group) was 101.5 minutes (72.5 to 134; P < 0.001). The proportion of patients who achieved a D2BT of ≤90 minutes increased from 39% in the pre-MonAMI group and 45% in the non-MonAMI group to 93% in the MonAMI group (P < 0.001).

Conclusions—The performance of prehospital 12-lead ECG triage and emergency department activation of the infarct team significantly improves D2BT and results in a greater proportion of patients achieving guideline recommendations. (Circ Cardiovasc Intervent. 2009;2:528-534.)

Key Words: myocardial infarction • electrocardiography

Total ischemic time affects mortality in those patients presenting with an ST-elevation myocardial infarction (STEMI). It is now well established that the time from onset of symptoms of acute myocardial infarction to definitive treatment is the key determinant of the degree of myocardial damage and loss and hence of morbidity and mortality. Shorter time intervals between onset of symptoms and restitution of blood flow to the ischemic myocardium results in improved outcomes.

Clinical Perspective on p 534

In patients with STEMI, the total ischemic time comprises patient-, transport-, and hospital-related delays. Community advice is to rapidly present for treatment on the occurrence of chest pain. Time from symptom onset to first contact with medical care, however, has been historically difficult to alter, requiring widespread community-based education from government and nongovernment organizations to affect change. Most attention from hospital-based health care providers, therefore, has been directed toward time to reperfusion from the time of first medical contact.

Optimal treatment of STEMI mandates rapid restoration of coronary flow and myocardial reperfusion. Primary percutaneous coronary interventions (PPCI) seems to be superior to thrombolytic therapy in achieving myocardial reperfusion if
performed in suitably trained and equipped centers. Because patients with shorter ischemic times have the better prognosis, hospital door-to-balloon time (D2BT)—the time from arrival in the emergency department (ED) to the first balloon inflation—has emerged as a valid quality-of-care indicator.8,9

McNamara et al10 report that D2BT is strongly associated with in-hospital mortality regardless of time from symptom onset or baseline risk. In-hospital mortality associated with reperfusion.1 A 10-year follow-up of high-risk patients presenting early with STEMI (>3 median delays in D2BT also impact late survival.5 It would therefore seem that minimizing D2BT has beneficial effects on short- and long-term patient outcome.

The accepted international minimum standard of care for achieving reperfusion is a hospital D2BT of <90 minutes.11 There will always be specific patient-related factors preventing rapid transfer to the cardiac catheter laboratory (CCL) and prompt revascularization, therefore 2007 American College of Cardiology/American Heart Association guidelines recommend >75% of patients receive PPPI within 90 minutes.12 Historically, this 90-minute goal is achieved in somewhere approaching only 40% of cases of PPPI.13 The advent of initiatives such as “D2B: An Alliance for Quality” and “Get with the Guidelines—CAD,” advocating widespread in-hospital system changes, has seen this figure improved to 67% in specific registries.14 In a review of 4278 patients in the United States transferred for PPPI between 1999 and 2002, Nallamothu et al15 found only 15.9% had a D2BT <2 hours. More recent data confirm only modest improvements in D2BT in patients requiring interhospital transfer.16

Prehospital triage of STEMI has been advocated as a means to avoid interhospital transfer and minimize hospital-based delays to improve D2BT.17 The decision of who activates the infarct team not only plays a substantial role in D2BT but also significantly affects the proportion of patients undergoing unnecessary angiography.18–20 We report here the influence in a large metropolitan hospital network of a system-wide and multidisciplinary approach to STEMI management with the implementation of paramedic performed 12-lead ECG-based triage of STEMI and ED activation of the infarct team on D2BT.

Methods

In June 2007, a pilot program was developed through collaboration between Ambulance Victoria, Southern Health Emergency, and MonashHEART (the cardiology services of Monash Medical Centre) to assess feasibility and results of implementing paramedic-based field triage system for chest pain patients. The tertiary referral center involved is part of a larger Australian metropolitan health care network containing 2 other hospitals with EDs but without PCI capability (PCI referring), 12 and 26 km away from the PCI-receiving hospital. The healthcare network covers an area of ≈2800 km² and provides care for a primary population of ≈850 000 people, extending to 1.2 million people for tertiary services.

Ambulance Service

A total of 20 ambulances regularly attend and transport patients within the health network. Seven are mobile intensive care ambulances (MICA), which are dispatched preferentially to patients with ischemic sounding chest pain. Four of the 7 MICA units servicing the region were equipped with the ability to perform and transmit 12-lead ECGs for the purposes of this study. Fifty of 260 MICA paramedics received specific education for the MonashHEART Acute Myocardial Infarction (MonAMI) study, consisting of a 4-hour session provided by the senior MICA paramedics and interventional cardiologists. Training included performance and transmission of a 12-lead ECG and STEMI recognition to lower false-positive rates and demand on the PCI-receiving ED. There was no prerequisite experience level for the MICA paramedics to participate in this project (experience ranged from <1 year to >25 years).

The ambulance service prospectively recorded time from ambulance arrival at scene to the arrival in hospital for all patients undergoing field 12-lead ECG triage. These ambulance times were compared with an historical control consisting of 120 patients with suspected myocardial infarction transferred to the PCI-receiving hospital by a MICA unit before the time of implementation of the field 12-lead ECG triage. Ten percent of ECGs recorded by the ambulance service were randomly audited by a blinded Cardiologist and Emergency physician to determine false-negative rates.

A full 12-lead ECG would be performed by a MICA paramedic in cases of suspected myocardial infarction. This would be interpreted by the MICA paramedic and wirelessly transmitted to a dedicated receiving station within the tertiary referral center ED if a STEMI was identified. The MICA paramedic would also verbally notify the ED physician (via telephone or radio) and transmit a simultaneous page to the ED physician and on-call Interventional cardiologist to alert of an incoming STEMI. Protocols were instituted so that the cardiologist would directly call the ED physician if not contacted within 10 minutes of receiving a page.

Infarct Team Activation

After confirmation of STEMI by an ED physician, the infarct team would be activated through a central switchboard operator after liaison with the interventional cardiologist (Figure 1). This pathway to activate the infarct team was streamlined at the time of the introduction of field ECG triage with the number of telephone calls required to activate the infarct team reduced from 4 to a maximum of 2. All members of the infarct team were expected to arrive within 30 minutes after notification of an infarct.

Patient Groups and Outcome Measurements

Between December 2007 and October 2008, the D2BT of patients assessed by field 12-lead ECG triage as having STEMI and subsequently underwent primary PCI at a single PCI-receiving center (MonAMI group) were prospectively compared with patients undergoing PPPI after arrival to the healthcare network without field 12-lead ECG (non-MonAMI group). The D2BT of an historical control group (preMonAMI group) was also prospectively assessed before the introduction of field 12-lead ECG (between June 2007 and December 2007). All patients who underwent PPPI, after presentation to the healthcare network, were included in the data. Assignment
to the MonAMI group was determined by the performance of a field 12-lead ECG, regardless of the success of transmission. Patients who self-presented to the ED and also presented by means of ambulance without 12-lead ECG capability were included in the pre- and non-MonAMI groups. Prespecified outcome measures were prospectively recorded: time to presentation, pain-to-balloon time, D2BT, door-to-CCL time, and CCL-to-balloon time.

Definitions
STEMI was defined as \( \geq 1 \) mm ST elevation (\( \geq 0.1 \) mV) in 2 contiguous leads or left bundle branch block, with chest pain or other appropriate clinical setting (ventricular fibrillation) as per American College of Cardiology/American Heart Association guidelines.\(^{21}\) Time of arrival was defined as time transferred into the ED if presenting by ambulance and triage time if self-presenting to hospital. Where there was a discrepancy between triage and cubical time, the earliest time was used. Balloon time was defined as the time of first balloon inflation or the first aspiration with an aspiration/thrombectomy device. CCL time was recorded from when the patient arrived in the CCL and not time on the table. In hours was defined as the usual working hours of the hospital—between 8:00 AM and 5:00 PM Monday to Friday; Out of hours, public holidays and all times outside of in hours.

Statistical Analysis
We calculated a sample size of 100 patients in the MonAMI group was required to demonstrate a 20-minute reduction in D2BT with a \( P \) value of 0.05 and power of 0.80 based on a historical mean D2BT of 102 minutes with a standard deviation of 57 minutes. We felt that the system changes implemented would generate at least a 20-minute reduction in D2BT in light of our historical data showing an ED to CCL time of \( >60 \) minutes (Bradley et al\(^{22}\) noting a 15.4-minute reduction for the ED to activate the infarct team while the patient is en route to the hospital). The pilot study was concluded at the end of the month in which 100 patients underwent PPCI through field 12-lead ECG triage. Statistical analysis was performed using SPSS 14 (SPSS Inc). For noncategorical normally distributed data (patient age), a 3-way ANOVA with Bonferroni correction was performed. For noncategorical noncontinuous data a Kruskal–Wallis or Mann–Whitney test was used when appropriate. Pearson \( \chi^2 \) tests were used for categorical data. All times represented are, unless specified, median times in minutes, with interquartile ranges, shown in square brackets. A \( P \) value of \(<0.05\) was deemed significant.

Results
Study Population
One hundred twenty patients underwent PPCI from June 2007 to the initiation of field ECG triage and ED activation of the infarct team in December 2007 (pre-MonAMI group). One hundred seven patients underwent field ECG triage from December 2007 to October 2008 (MonAMI group) with 122 patients available as a contemporary control, not receiving prehospital triage but with activation of the infarct team through the ED physician (non-MonAMI group). The patient demographics and time of presentation are detailed in Table 1. The 3 groups were similar, apart from a modest difference

<table>
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<tr>
<th>Table 1. Patient Demographics and Presentation Details for the 3 Defined Groups</th>
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<td>Total patients</td>
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<tr>
<td>Male</td>
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<tr>
<td>Age, y (±SD)</td>
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<td>Hypertension</td>
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<td>Diabetes</td>
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<td>Presenting hospital</td>
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<td>PCI receiving</td>
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<td>Hospital 2§</td>
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<td>Presentation time</td>
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<td>3 to 6 h</td>
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<td>&gt;6 h</td>
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*There is a statistical difference between the pre-MonAMI and MonAMI groups, \( P = 0.03 \) using Bonferroni correction. †Hospital 1 is the PCI referring hospital 12 km away from the PCI receiving hospital. ‡Signifies a 2-way sample between pre- and non-MonAMI groups. §Hospital 2 is the PCI-referring hospital 26 km away from the PCI-receiving hospital.
in age and the proportion of patients with a history of hypertension.

**Ambulance Times**

Performance and transmission of a 12-lead ECG increased the average time of assessment by the MICA paramedics in the community before transportation to hospital by 3.7 minutes compared with the historical control (20.3 minutes before 12-lead ECG, 24.0 minutes for patients with STEMI receiving field 12-lead ECGs, *P*<0.001). There was no significant difference in average transport times (16.5 minutes before 12-Lead ECG, 17.8 minutes field 12-lead ECG, 24.0 minutes for patients with STEMI before 12-lead ECG, 17.8 minutes field 12-lead ECG, 24.0 minutes for patients with STEMI receiving field 12-lead ECGs, *P*=0.31).

**Twelve-Loot Project—MonAMI**

From December 2007 to October 2008, 204 ECGs were performed and faxed to the ED, resulting in 119 patients transferred to the CCL with suspected STEMI. A random audit consisting of 10% of field ECGs was reviewed by an independent cardiologist and ED physician. There were no false-negative results at either the paramedic or the ED stages—all patients with STEMI as a discharge diagnosis were identified and appropriately transferred to the CCL. Eighty-five faxed ECGs did not meet STEMI criteria (Figure 2). Of those stood down in the ED, no cases of STEMI were subsequently identified, 33 patients were discharged from the hospital with a diagnosis of either non-STEMI or unstable angina (acute coronary syndrome group). Three patients had severe triple vessel or left main disease and became pain-free before the transfer to the CCL. These patients proceeded to coronary artery bypass grafting. In 1 patient, the lesion was unable to be crossed with the guide wire. Eight patients transferred to the CCL had no significant coronary artery disease.

**D2BT**

The median D2BT (Table 2) was 101.5 (interquartile range, 72.5 to 134) minutes in the pre-MonAMI group compared with 98 (73 to 126.45) minutes in the non-MonAMI group and 56 (36.5 to 70) minutes in the MonAMI group (*P*<0.001). The reduction in the D2BT was driven by a reduction in the door-to-CCL time (68 [40 to 92] minutes in the pre-MonAMI group, 69 [40 to 94.5] minutes in the non-MonAMI group and 28 [13 to 39] minutes in the MonAMI group, *P*<0.001). The CCL to balloon (CCL2B) time was not significantly different between the groups (28 [22 to 37], 28 [23 to 39], and 26 [22 to 33] minutes for the pre-, non-, and MonAMI groups, respectively. The percentage of cases achieving a D2BT of <90 minutes was 38% in the pre-MonAMI group, 45% for the non-MonAMI group, and 93% for the MonAMI group (*P*<0.001; Figure 3). The percentage of cases achieving a D2BT of <90 minutes of the PCI-receiving hospital alone is 48%, 57%, and 93% in the pre-, non-, and MonAMI groups, respectively (*P*<0.001; Figure 4).

**Discussion**

Paramedic-performed field 12-lead ECG triage and prehospital activation of the infarct team by an emergency physician significantly improved D2BT and resulted in a greater proportion of patients achieving guideline recommendations. This reduction in median D2BT was driven by a reduction in the door-to-CCL time. There was no difference in the time to reperfusion once a patient arrived in the CCL, despite a significant reduction in the time spent in ED. The performance of the field ECG does not result in a substantial increase in the time from first medical contact to arrival in hospital.

Bradley et al22 have previously identified 6 factors, which improved median D2BT: emergency medicine physician activating the catheterization laboratory, a single call to a central page operator to activate the laboratory, ED activation of the CCL while the patient is en route to hospital, an expectation for staff to arrive in the catheterization laboratory within 20 minutes after notification (versus >30 minutes), an attending cardiologist always on duty, and an in-room emergency procedure coach.
site, and staff in the ED and the catheterization laboratory using real-time data feedback.

The MonAMI pilot project examined, in a prospective manner, system-wide changes to reduce D2BT. Comparison of the MonAMI group with the non-MonAMI group specifically examined activation of the PPCI team while the patient is en route to hospital (field 12-lead ECG). Comparison of the pre- and non-MonAMI groups examined ED activation of the infarct team. These 2 factors are listed by Bradley et al\textsuperscript{22} to significantly improve D2BT.

We noted a trend for a reduction in the median D2BT with ED activation and a streamlined infarct team activation pathway (10.5 minutes $P=\text{NS}$), and hence a greater proportion of patients meeting guideline times (Figure 4), in patients presenting to the PCI-receiving hospital. This is consistent with findings from Bradley et al\textsuperscript{22} who noted an 8.2-minute reduction in D2BT. The significant factor contributing to the overall reduction in D2BT, as seen in the MonAMI group, was prehospital triage. This improvement was made without a significant number of patients undergoing unnecessary coronary angiography. More than 93% of patients receiving prehospital triage and transferral to the CCL had significant coronary artery disease, a finding consistent with previously published rates,\textsuperscript{20} where ED physicians were directly responsible for admitting patients to the CCL.

Forty percent of patients with transmitted ECGs did not proceed to the CCL, which is higher than other published rates where paramedics are directly responsible for activating the infarct team.\textsuperscript{18} Despite inclusion in the analysis, the sending of an ECG did not automatically result in infarct team activation, and as such paramedics were not discouraged from sending ECGs that may be clinically helpful but not meeting STEMI criteria (eg, cardiac arrhythmias). We believe that this fact, along with a learning curve to the interpretation of ECGs, contributed to the higher rate of false-positive ECG transmissions seen.

Most presentations in our cohort were out of hours, consistent with other reports,\textsuperscript{23} underscoring the importance of measures targeting improvement in D2BT for those patients presenting outside the normal working hours of the CCL. The proportion of patients in the MonAMI group meeting guideline recommendations of a D2BT <90 minutes was not affected by time of presentation (92% in hours versus 95% out of hours).

Although guideline recommendations were achieved in the MonAMI group regardless of time of presentation, there was, as expected,\textsuperscript{19,24} a significant difference between the median D2BT of the “in hours” and “out of hours” cohorts. Hospital protocol required the infarct team to arrive within 30 minutes of notification (not 20 minutes as identified by Bradley et al\textsuperscript{22}). There was also no onsite cardiologist after hours. These 2 factors are recommended to reduce the disparity between in and out of hours D2BT but significantly increase the demand on resources and overall cost.

There have been arguments to implement tighter D2BTs in patients presenting within the first hour after onset of chest pain, as reflected in some international guidelines.\textsuperscript{25} The out of hour median D2BT was 25.5 minutes (D2BT=62 minutes) more than that of the in hours population in the MonAMI group, and so if these tighter goals were applied, $\approx 50\%$ of patients presenting within the first hour would have fallen out of these recommended timeframes. Overall, the non- and pre-MonAMI groups contained $\approx 15\%$ of patients presenting within 1 hour of commencement of symptoms, and so the current accepted paradigm is applicable for the significant majority of patients. Also, this “golden hour rule” assumes rapid administration of thrombolytic therapy ($<30$ minutes door-to-needle time), a potentially misplaced assumption in

\begin{figure}
\centering
\includegraphics[width=\textwidth]{Figure3}
\caption{Bar graph displaying the percentage of cases with a D2BT under 90 minutes for patients presenting to the hospital network for the 3 defined groups. In hours indicates times between 8:00 AM and 5:00 PM Monday to Friday; Out of hours, public holidays and all times outside of in hours. $^*P<0.001$.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{Figure4}
\caption{Bar graph displaying the percentage of cases with a D2BT under 90 minutes for patients presenting to the PCI-receiving hospital for the 3 defined groups. In hours indicates times between 8:00 AM and 5:00 PM Monday to Friday; Out of hours, public holidays and all times outside of in hours. $^*P<0.001$.}
\end{figure}
light of registry data reporting only \( \approx 39\% \) of patients in the United States receive thrombolysis within 30 minutes.\(^{14}\)

Despite quality improvement initiatives improving D2BT in some registries,\(^{14}\) there has been no substantial improvement in D2BT of patients transferred from peripheral sites.\(^{15,16}\) Field triage enables PCI-referring hospital bypass, reducing the significant time delay of intrahospital transfer.\(^{19}\) This inevitably leads to an increased number of patients arriving in the PCI-receiving ED. We found the 40% false-positive rate of field 12-lead ECG triage combined with \( \approx 25\% \) of patients undergoing PPCI transferred from PCI referring hospitals would result in a further 16 patients inappropriately transferred to the PCI-receiving ED for every 100 STEMI treated (Table 3). However, this extra patient load is counterbalanced by a reduction in the time spent in ED for all other patients awaiting PPCI (\( \approx 25 \) hours in ED saved per 100 patients). Peripheral hospital bypass also negates the requirement for further interhospital transfer of both patients with STEMI (25 transfers per 100 PPCI procedures) and other acute coronary syndrome patients undergoing early interventional management (40% of patients stood down in the ED were discharged with a diagnosis of unstable angina or non-STEMI).

The MonAMI project significantly reduced D2BT and increased the proportion of patients achieving guideline recommendations by introducing system-wide changes involving paramedic, ED, and interventional cardiac levels of care for patients presenting with STEMI. This was achieved while maintaining a low incidence of unnecessary transfers to the CCL and without a significant increased demand on paramedic or ED resources.

**Limitations**

Clocks used to document critical times were not synchronized to the atomic clock, leading to possible inaccuracy. However, the clocks used were synchronized throughout the healthcare network and were consistent among the 3 groups. Further attempts were made to minimize inaccuracies by using times resulting in the longest D2B or CCL2B time where any possible discrepancies arose. We believe this would have minimal impact on our results. The healthcare network is situated in a highly urbanized community using 1 high-volume PCI-receiving institution with 2 PCI-referring hospitals within the network. Although D2BT is a quality key performance indicator, it is however a surrogate marker for mortality. Whether these significant D2BT reductions translate to improved mortality and morbidity outcomes is the subject of an ongoing study.

**Acknowledgments**

The MonAMI project was established through the collaborative efforts of Ambulance Victoria, Southern Health Emergency, MonashHeart, and Southern Healthcare network. We appreciate the dedication and professionalism shown by the many MICA paramedics, Emergency Department, Cardiac Catheter Laboratory, and Coronary Care staff. We also acknowledge K. Barker, S. Sabir, F. Webster, and M. Zhang for their work on this project and the National Heart Foundation (Australia) for their continuing support for health prevention initiatives.

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**Disclosures**

None.

**References**


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**Table 3. The D2BT in Minutes for the 5 Defined Groups**

<table>
<thead>
<tr>
<th></th>
<th>PCI Receiving Hospital</th>
<th>PCI Referring Hospitals</th>
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<tr>
<td></td>
<td>Pre-MonAMI</td>
<td>Non-MonAMI</td>
</tr>
<tr>
<td>Total, min</td>
<td>94 (62 to 120)</td>
<td>83.5 (65.5 to 113)</td>
</tr>
<tr>
<td>In hours, min</td>
<td>75 (45.5 to 103.5)</td>
<td>80.5 (57 to 100)</td>
</tr>
<tr>
<td>Out of hours, min</td>
<td>100.5 (77 to 120)</td>
<td>93 (70 to 113)</td>
</tr>
</tbody>
</table>

All values are median times in minutes with interquartile ranges in parentheses. In hours indicates times between 8:00 AM and 5:00 PM Monday to Friday; Out of hours, public holidays and all times outside of in hours.

*Denotes the comparison between the MonAMI and the 4 other defined groups.
The MonashHEART acute myocardial infarction project adds to the growing body of evidence supporting the use of prehospital triage to improve patient care in the management of ST-elevation myocardial infarction. It supports initiatives aimed at incorporating a multidisciplinary approach to minimize door-to-balloon time. Furthermore, these system improvements do not shift the burden of care or significantly consume resources of individual stakeholders who provide the various components of optimal ST elevation myocardial infarction management.

CLINICAL PERSPECTIVE
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