ABSTRACT
Objective To establish whether a novel accelerated diagnostic protocol (ADP) for suspected acute coronary syndrome (ACS) could successfully identify low-risk patients suitable for discharge after a single high-sensitivity troponin T (hs-cTnT) taken at presentation to the emergency department. We also compared the diagnostic accuracy of this ADP with strategies using initial undetectable hs-cTnT.
Methods This prospective observational study evaluated the ability of the Triage Rule-out Using high-Sensitivity Troponin (TRUST) ADP to identify low-risk patients with suspected ACS. The ADP incorporated a single presentation hs-cTnT of <14 ng/L, a non-ischaemic ECG and a modified Goldman risk score. Diagnostic performance of the ADP was compared with the detection limit cut-offs of hs-cTnT (<5 ng/L and <3 ng/L). The primary end point was fatal/non-fatal acute myocardial infarction (AMI) within 30 days.
Results 960 participants were recruited, mean age 58.0 years, 80 (8.3%) had an AMI. The TRUST ADP classified 382 (39.8%) as low-risk with a sensitivity for identifying AMI of 98.8% (95% CI 92.5% to 99.9%). hs-cTnT detection limits (<5 ng/L and <3 ng/L) had a sensitivity of 100% (94.3 to 100) and 100% (94.4 to 100), respectively. The TRUST ADP identified more patients suitable for early discharge at 39.8% vs 29.3% (<5 ng/L) and 7.9% (<3 ng/L) (p<0.001) with a lower false-positive rate for AMI detection; specificity 43.3% (95% CI 42.7% to 44.3%) vs 32.0% (95% CI 31.5% to 32.0%) and 8.6% (95% CI 8.1% to 8.6%), respectively.
Conclusions The TRUST ADP, which incorporates structured risk-assessment and a single presentation hs-cTnT blood draw, has potential to early discharge in 40% of patients with suspected ACS and has greater clinical utility than undetectable hs-cTnT strategies.
Primary end point: fatal/non-fatal acute myocardial infarction (AMI)
Secondary end points: serum creatine kinase (CK) and CK-MB
Risk assessment protocols: modified Goldman score
Laboratory measurement: high-sensitivity troponin T (hs-cTnT)

INTRODUCTION
Patients with suspected acute coronary syndrome (ACS) make up to 10% of all emergency department (ED) attendances and 25% of acute hospital admissions. Current guidelines recommend two serial measurements of non-high-sensitivity troponin between 6 h and 12 h after patient presentation to the ED. As a result, the majority of patients require prolonged assessment prior to safe discharge despite the fact that only 15–25% of these patients have a final diagnosis of ACS.
Consensus reports suggest that high-sensitivity troponin (hs-cTn) assays may be used to reduce door-to-discharge times by using serial testing over 3–6 h. Investigators have reduced blood draw times further by incorporating structured clinical risk assessment protocols with hs-cTn, or analysing δ change over time. Despite successfully identifying between 40% and 60% of low-risk patients, these algorithms still require serial testing of hs-cTn which will delay discharge from the ED. This delay may be associated with significant healthcare costs, and contribute to ED overcrowding.
To address these issues, several studies have investigated the effectiveness of a single undetectable hs-cTn value taken at presentation to the ED in identifying those at very low risk of acute myocardial infarction (AMI). Despite demonstrating promising results as a rule-out strategy for AMI, this protocol has not been recommended by expert guidelines due to concerns over assay analytical interference and poor test specificity. Therefore, a clinically applicable protocol that allows the discharge of a significant proportion of patients after just a single hs-cTn blood draw at presentation remains an attractive yet elusive goal.
Using binary hs-cTn results alone to guide discharge decisions fails to use a wealth of clinical information available to treating physicians. The Goldman risk score uses simple variables that are immediately available to the ED physician and are derived from the history, examination and ECG findings. Since its inception, the score has been modified to improve physician decision making in the identification of low-risk patients. This has led to improved use of hospital resources. Despite achieving the highest level of evidentiary support for use in ED patients with chest pain the modified Goldman (m-Goldman) risk score remains untested as a discharge tool in combination with a single presentation hs-cTn.

The Triage Rule-out Using high-Sensitivity Troponin (TRUST) study’s primary aim was to establish whether a novel accelerated diagnostic protocol (ADP) for patients with suspected ACS consisting of hs-cTn, a non-ischaemic ECG and the m-Goldman score, could successfully identify low-risk patients suitable for discharge after a single blood draw at presentation to the ED. Secondary aims were to compare the diagnostic accuracy of the ADP with strategies using initial undetectable hs-cTnT levels.
METHODS
This prospective observational clinical trial was designed to assess the predefined TRUST ADP. The protocol was designed to be truly pragmatic in order to enhance the widespread applicability of the study results; with attending clinicians performing m-Goldman risk scores, rostered clinical (not research) staff undertaking blood sampling, real-time sample processing and 24/7 recruitment. The study was designed using the Standards for Reporting Diagnostic Accuracy, and approved by the UK National Research Ethics Service. All participants provided written informed consent. The TRUST study was registered with the Controlled Trials Database (ISRCTN No. 21109279) and complies with the Declaration of Helsinki.

Study setting, recruitment and data collection
Poole NHS Foundation Trust is a UK District General Hospital, its ED has approximately 62,000 new patient attendances per year. Patients with suspected ACS are managed according to the local hospital protocol, which involves risk assessment by ED physician staff using the m-Goldman risk score and blood drawn for hs-cTnT at 6 h after presentation. As part of the study protocol, blood was also taken at presentation for hs-cTnT analysis. While historical clinical protocols, at the time of this study, did not include troponin measurement at presentation, this had the benefit of ensuring that treating physicians were blinded to the initial hs-cTnT result to avoid selection bias.

The fifth generation Roche ELECSYS hs-cTnT assay (Roche, Switzerland), which has a limit of detection (lowest analyte concentration likely to be reliably distinguished from the limit of blank at which detection is feasible) of 5 ng/L, limit of blank (highest apparent analyte concentration expected to be found when replicates of a blank sample containing no analyte are tested) of 3 ng/L, 99th percentile of 14 ng/L and 10% coefficient of variation of <10% at 9 ng/L, was used for research (presentation) and reference (6-h) samples. During initial assessment clinical staff drew blood for routine admission samples and an additional 3.5 mL of whole blood in a prelabelled study-specific serum settling tube for hs-cTnT analysis. All serum samples were tested in real time.

Consecutive patients attending the ED with suspected ACS were prospectively screened from July 2012 to August 2013. Patients were included if they were at least 18 years of age and had at least 5 min of chest pain suggestive of ACS, and for whom the attending physician determined inpatient evaluation was required. Possible cardiac symptoms included acute chest, epigastric, neck, jaw or arm pain, or discomfort or pressure without an apparent non-cardiac source, in accordance with the American Heart Association case definitions. Patients were excluded if any of the following were present: ST-segment elevation myocardial infarction or left bundle branch block not known to be old, ECG changes diagnostic of ischaemia (ST-segment depression ≥1 mm or T-wave inversion consistent with the presence of ischaemia), arrhythmias (new-onset atrial fibrillation, atrial flutter, sustained supraventricular tachycardia, second-degree or complete heart block, or sustained or recurrent ventricular arrhythmias), hs-cTnT not suitable for analysis (eg, haemolysis), age ≥80 years, atypical symptoms in the absence of chest discomfort, a clear non-ACS cause for chest pain was found at presentation (eg, pulmonary embolism, pneumonia, aortic dissection), another medical condition requiring hospital admission, refusal or inability to give informed consent, non-English speaking, pregnancy, renal failure requiring dialysis or inability to be contacted after discharge.

Data were collected prospectively using a published data dictionary. Attending ED clinicians completed the m-Goldman risk score on a redesigned clinical report form. Follow-up was undertaken by independent review of hospital electronic patient records, summary of health records from the patient’s general practitioner (GP) obtained at least 6 months after attendance and a national clinical records search (which identifies death). The ethics committee did not grant permission for direct patient contact as they felt that comprehensive follow-up data relating to adverse events could be obtained accurately through GP records. This is because in the UK, GPs hold comprehensive records for individuals relating to primary, secondary and tertiary care. GP records have been demonstrated to be more accurate at reporting hospital admissions, including those for cardiac related events, than patients. GPs were therefore requested to provide all information regarding presentation to other institutions with chest pain, cardiology outpatient review and cardiac testing, including angiography with or without intervention. Where a participant had not attended hospital follow-up and/or a GP had failed to provide a health record/not GP-registered, the patient was regarded as lost to follow-up.

Index tests
The primary index test was the TRUST ADP (table 1), this defined a patient as ‘low-risk’ if all of the following conditions were satisfied at presentation: a m-Goldman Score of 0 or 1, a non-ischaemic ECG and a single central laboratory hs-cTnT of <14 ng/L at presentation.

Secondary index tests were the detection limits for hs-cTnT (5 ng/L and 3 ng/L) and non-ischaemic ECG at presentation.

Outcome measures
The primary end point was the presence of fatal or non-fatal AMI occurring within 30 days of hospital attendance (including the index visit).

The presence of AMI was defined according to the Third Universal Definition of MI which states that a rise and/or fall in
troponin, with at least one value above the 99th centile in the context of a patient with ischaemic symptoms or signs (ECG changes or imaging evidence) would satisfy the diagnosis.\textsuperscript{18}

Based on current consensus guidance for hs-cTn assays, a rise or fall of 20% (\(\delta\)) was considered statistically significant and consistent with a diagnosis of AMI.\textsuperscript{3} Adjudication of the primary end point was carried out by two local cardiologists blinded to the m-Goldman score but who had access to the clinical record, ECG and serial hs-cTnT results. If a troponin result was above the 99th centile value and a non-ischaemic cause of troponin elevation was identified this was considered by the adjudicating cardiologist in accordance with expert consensus.\textsuperscript{19}

The presence of major adverse cardiac events (MACEs) occurring within 30 days of hospital attendance (including the index visit) was a secondary outcome measure. MACE included: death due to ischaemic heart disease, cardiac arrest, urgent revascularisation, cardiogenic shock, ventricular arrhythmia, high-degree atrioventricular block needing intervention and AMI. MACE was defined according to previous large scale studies assessing the safety of rapid discharge protocols.\textsuperscript{4,20,21}

\begin{table}
\centering
\begin{tabular}{lccc}
\hline
 & Fatal/non-fatal AMI positive at 30 days (N=80) & TRUST ADP intermediate/high risk (N=578) & TRUST ADP low risk (N=382) \\
\hline
Age, years (Mean±SD) & 63.3±10.6 & 60.4±12.8 & 55.6±19.4 \\
Sex (% male) & 53 (66.3) & 360 (62.3) & 205 (53.7) \\
Ethnicity (% British Caucasian) & 94 (95.2) & 549 (95.0) & 365 (95.5) \\
Risk factors N (%) & & & \\
Hypertension & 45 (73.8) & 319 (55.2) & 123 (34.8) \\
Diabetes & 164 (17.1) & 124 (21.4) & 40 (10.5) \\
Dyslipidaemia & 635 (66.1) & 429 (74.2) & 206 (53.9) \\
Smoking current & 231 (24.1) & 129 (22.3) & 102 (26.7) \\
Smoker ex & 343 (35.1) & 229 (39.6) & 114 (29.8) \\
Family history of coronary artery disease & 72 (90.0) & 549 (95.0) & 365 (95.5) \\
Medical history & & & \\
Angina & 251 (26.1) & 207 (35.8) & 44 (11.5) \\
Myocardial infarction & 204 (21.3) & 174 (30.1) & 30 (7.9) \\
Percutaneous coronary intervention & 183 (19.1) & 146 (25.3) & 37 (9.7) \\
Congestive cardiac failure & 30 (3.1) & 25 (4.3) & 5 (1.3) \\
Atrial arrhythmia & 119 (12.4) & 86 (14.9) & 33 (8.6) \\
Stroke & 63 (6.6) & 45 (7.7) & 18 (4.7) \\
Coronary artery bypass graft & 50 (5.2) & 41 (7.1) & 9 (2.4) \\
Baseline medications & & & \\
Aspirin & 361 (37.6) & 276 (47.8) & 85 (22.3) \\
Clopidogrel & 112 (11.7) & 84 (14.5) & 28 (7.3) \\
β blocker & 281 (29.3) & 210 (36.3) & 71 (18.6) \\
ACE inhibitor & 272 (28.3) & 195 (33.7) & 77 (20.2) \\
Statin & 369 (38.4) & 276 (47.8) & 93 (24.3) \\
Median length of hospital stay (h)±IQR & 107.5±110.3 & 22.4±62.0 & 14.0±11.9 \\
\hline
\end{tabular}
\caption{Patient characteristics}
\end{table}
Coronary artery disease

Statistical analysis
Baseline characteristics of the study population were analysed with conventional group descriptive statistics. Diagnostic protocol results and outcome status were cross-tabulated to permit calculation of sensitivity, specificity, negative predictive value (NPV), positive predictive value, positive likelihood ratio and negative likelihood ratio. Statistical significance was evaluated using McNemar’s test. All statistical analysis was carried out using SPSS V.20.

RESULTS
Nine hundred and sixty-four consenting patients were recruited (figure 1), Four patients were lost to follow-up (health records pertaining to presence of outcome measures unobtainable) meaning that 99.6% were successfully monitored for 30 days. However, no patient lost to follow-up died within 30 days of attendance. Participants were predominantly white, older men who commonly had risk factors for coronary artery disease (table 2). Of the patients 80/960 (8.3%) had a primary outcome event (fatal or non-fatal AMI) and 97/960 (10.1%) had a MACE within 30 days, and 30/960 (3.1%) patients had a non-ischaemic cause of hs-cTnT elevation above the 99th centile identified (diagnoses summarised in the online supplementary appendix). Patients presented to the ED at a median of 2 h 20 min (IQR ± 22.8 min) after chest pain onset. Blood was taken for hs-cTnT at a median of 35 min (IQR ± 14 min) after patient arrival.

Diagnostic accuracy of the TRUST ADP
The TRUST ADP classified 382/960 (39.8%) of patients as at low risk of fatal or non-fatal AMI (table 3), with a sensitivity for identifying AMI of 98.8% (95% CI 92.4% to 99.9%) and NPV of 99.7% (95% CI 98.4% to 100%) and had a similar diagnostic performance for the secondary outcome measure (MACE) (table 4).

A single patient (0.3%) classified as low-risk by the TRUST ADP had an AMI during the initial hospital attendance and follow-up. This patient was a 78-year-old woman classified as low-risk on the m-Goldman score and had a hs-cTnT of 13 ng/L at presentation. However, a minor hs-cTnT elevation to 20 ng/L (Δ change 27%) occurred on the second hs-cTnT test at 6 h and was therefore diagnosed with an AMI. The patient was medically managed and had no further complications.

Undetectable troponin strategies
The diagnostic performance of hs-cTnT limit of detection cut-off values in patients with a non-ischaemic ECG are shown in table 4. By using the limit of detection cut-off value of 5 ng/L for the primary outcome measure (AMI) the sensitivity was 100% (95% CI 94.3% to 100%) and 270/922 (29.3%) of patients were eligible for early discharge (table 3). However, using the secondary outcome measure (MACE), three patients (1.1%) identified as suitable for discharge using this strategy required urgent revascularisation (all three were aged in their 40s, two had severe left anterior descending artery disease and one severe right coronary artery disease). Using the limit of blank (<3 ng/L) the sensitivity for fatal/non-fatal AMI was 100% (95% CI 94.4% to 100%) and only 7.9% would have been eligible for early discharge. One patient (1.4%) with a hs-cTnT <3 ng/L required urgent revascularisation.

Comparison of strategies
The TRUST ADP identified significantly more patients suitable for immediate discharge at 39.8% vs 29.3% (<5 ng/L) and 7.9% (<3 ng/L) (p < 0.001) with a lower false-positive rate for AMI detection; specificity 43.3% (95% CI 42.7% to 43.4%) vs 32.0% (95% CI 31.5% to 32.0%) and 8.6% (95% CI 8.1% to 8.6%) respectively, while maintaining a high diagnostic accuracy for the rule-out of AMI.

DISCUSSION
This study demonstrates that the TRUST ADP for suspected ACS can successfully identify 40% of patients as low-risk after just a single hs-cTnT taken at presentation to the ED, with a NPV of >99.5%. When compared with strategies using undetectable hs-cTnT, more patients are eligible for early discharge with lower false-positive rates, suggesting this approach has greater clinical utility. Furthermore, by incorporating clinical risk stratification, the TRUST ADP has improved accuracy in identifying those who require urgent revascularisation.

Our results suggest that the introduction of this ADP has the potential to reduce the length of stay for low-risk patients (currently 14 h in our institution) after a single laboratory-based troponin and avoid the necessity for two separate blood draws. Uptake of this protocol may have significant benefits for healthcare services worldwide by reducing hospital admission rates, ED overcrowding, duplication of staff time and resource use. Furthermore, by using ED physicians to carry out risk stratification and real-time troponin sampling with 24-h recruitment we have demonstrated that this ADP is truly applicable.

This analysis confirms the results of recent large-scale exploratory research that showed undetectable hs-cTnT held promise as a tool for rule-out of AMI or death.6 However, we demonstrate that by using MACE (which also includes urgent revascularisation) missed-event rates of the undetectable troponin strategies

Table 3 Occurrence of fatal/non-fatal AMI and MACE during the index hospital visit or at 30 days according to index test

<table>
<thead>
<tr>
<th>Test</th>
<th>AMI</th>
<th>No AMI</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRUST ADP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not low risk</td>
<td>79</td>
<td>499</td>
<td>578</td>
</tr>
<tr>
<td>Low risk</td>
<td>1</td>
<td>381</td>
<td>382</td>
</tr>
<tr>
<td>Hs-cTnT&lt;5 ng/L*</td>
<td>≥5 ng/L</td>
<td>78</td>
<td>574</td>
</tr>
<tr>
<td>&lt;5 ng/L</td>
<td>0</td>
<td>270</td>
<td>270</td>
</tr>
<tr>
<td>Hs-cTnT&lt;3 ng/L*</td>
<td>≥3 ng/L</td>
<td>78</td>
<td>771</td>
</tr>
<tr>
<td>&lt;3 ng/L</td>
<td>0</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>TRUST ADP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not low risk</td>
<td>96</td>
<td>482</td>
<td>578</td>
</tr>
<tr>
<td>Low risk</td>
<td>1</td>
<td>381</td>
<td>382</td>
</tr>
<tr>
<td>Hs-cTnT&lt;5 ng/L*</td>
<td>≥5 ng/L</td>
<td>92</td>
<td>560</td>
</tr>
<tr>
<td>&lt;5 ng/L</td>
<td>3</td>
<td>267</td>
<td>270</td>
</tr>
<tr>
<td>Hs-cTnT&lt;3 ng/L*</td>
<td>≥3 ng/L</td>
<td>94</td>
<td>755</td>
</tr>
<tr>
<td>&lt;3 ng/L</td>
<td>1</td>
<td>72</td>
<td>73</td>
</tr>
</tbody>
</table>

*922/960 (96%) results are reported for the hs-cTnT detection limits. This was due to computer error whereby 38 results were only reported as <14 ng/L.

AMICorert AUU, ACUT, ACUT, TRUST, Triage Rule-out Using high-Sensitivity Troponin.
Table 4 Diagnostic accuracy of TRUST ADP and detection limit cut-offs of hs-cTnT for the prediction of fatal/non-fatal AMI and MACE in patients with a non-ischaemic ECG

<table>
<thead>
<tr>
<th>Percentage of eligible for early discharge</th>
<th>Number of events (%)</th>
<th>Sensitivity (95% CI)</th>
<th>NPV (95% CI)</th>
<th>Specificity (95% CI)</th>
<th>PPV (95% CI)</th>
<th>+LR (95% CI)</th>
<th>−LR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary outcome fatal/non-fatal AMI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRUST ADP Low risk</td>
<td>0/270 (0.0)</td>
<td>100 (94.4 to 100)</td>
<td>98.9 (94.3 to 100)</td>
<td>31.0 (30.6 to 31.5)</td>
<td>11.5 (11.1 to 11.9)</td>
<td>1.41 (1.32 to 1.50)</td>
<td>0.002 (0.000 to 0.061)</td>
</tr>
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<td>hs-cTnT &lt;5 ng/L</td>
<td>0/270 (0.0)</td>
<td>100 (94.4 to 100)</td>
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<td>11.5 (11.1 to 11.9)</td>
<td>1.41 (1.32 to 1.50)</td>
<td>0.002 (0.000 to 0.061)</td>
</tr>
<tr>
<td>Secondary outcome MACE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRUST ADP Low risk</td>
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<td>100 (94.4 to 100)</td>
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<td>0.002 (0.000 to 0.061)</td>
</tr>
</tbody>
</table>

ADP, accelerated diagnostic protocol; AMI, acute myocardial infarction; hs-cTnT, high-sensitivity troponin T; +LR, positive likelihood ratio; −LR, negative likelihood ratio; MACE, major adverse cardiac event; NPV, negative predictive value; PPV, positive predictive value.

What is already known on this subject?
The use of undetectable high-sensitivity troponin levels and risk scores in combination with early biomarker testing have recently been put forward as diagnostic tools aiming to reduce door-to-discharge times in patients with suspected acute coronary syndromes. However, a clinically applicable protocol that allows the discharge of a significant proportion of patients after just a single high sensitivity troponin blood draw at presentation to the emergency department remains an attractive yet elusive goal.

What might this study add?
Using a simple clinical risk score, together with the results of a single high-sensitivity troponin result, the Triage Rule-out Using high-Sensitivity Troponin accelerated diagnostic protocol, may enable immediate discharge in up to 40% of patients. This strategy identifies more patients suitable for early discharge, with lower false-positive rates than undetectable troponin strategies.

How might this impact on clinical practice?
Chest pain makes up a quarter of medical admissions in the UK. A diagnostic strategy that prevents unnecessary hospital admission in a large proportion of this patient group would have significant benefits for healthcare services by reducing hospital admission rates, emergency department overcrowding, duplication of staff time and resource use.
We recognise that the TRUST ADP now requires validation as part of a multicentre randomised controlled trial. However, without first analysing the safety of this diagnostic strategy through an observational cohort design, the principle of clinical equipoise may not have justified a randomised study design. 23

CONCLUSION
The TRUST ADP, which incorporates a structured risk-assessment and single presentation hs-cTnT blood draw, has the potential to allow early discharge in 40% of patients with suspected ACS. This ADP has superior clinical utility when compared with undetectable hs-cTnT strategies. Future research should focus on methodologies that incorporate clinical assessment with hs-cTnT testing rather than troponin testing alone.

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Contributors Each author has contributed to the analysis and interpretation of the data, and drafting and approval of the final manuscript. All authors have also contributed to the conception/design of the study reported in this manuscript.

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Competing interests EWC has received funding from Abbott in support for related research. LC has received funding from Abbott, Roche, Alere, Siemens and Radiometer Pacific for clinical trials, and from Alere, Boehringer Ingelheim, Pfizer, Astra Zeneca, Abbott, Novartis and Radiometer Pacific for speaking and education. MT has received funding from Alere, Abbott, Beckman and Roche for speaking and support for other research. KG has received funding from AstraZeneca and Takeda UK for related research.

Patient consent Obtained.

Ethics approval Frenchay Research Ethics Committee (reference 12/SW/0133).

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement All requests for further data from this study should be addressed to the corresponding author.

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A novel diagnostic protocol to identify patients suitable for discharge after a single high-sensitivity troponin

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