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CHEST RADIOLOGY

First-line sonographic diagnosis of pneumothorax in major trauma: accuracy of e-FAST and comparison with multidetector computed tomography

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Abstract

Purpose Combined clinical examination and supine chest radiography have shown low accuracy in the assessment of pneumothorax in unstable patients with major chest trauma during the primary survey in the emergency room. The aim of our study was to evaluate the diagnostic accuracy of extended-focused assessment with sonography in trauma (e-FAST), in the diagnosis of pneumothorax, compared with the results of multidetector computed tomography (MDCT) and of invasive interventions (thoracostomy tube placement).

Materials and methods This was a retrospective case series involving 368 consecutive unstable adult patients (273 men and 95 women; average age, 25 years; range, 16–68 years) admitted to our hospital's emergency department between January 2011 and December 2012 for major trauma (Injury Severity Score $\geq$ 15). We evaluated the accuracy of thoracic ultrasound in the detection of pneumothorax compared with the results of MDCT and invasive interventions (thoracostomy tube placement). Institutional review board approval was obtained prior to commencement of this study.

Results Among the 736 lung fields included in the study, 87 pneumothoraces were detected with thoracic CT scans (23.6 %). e-FAST detected 67/87 and missed 20 pneumothoraces (17 mild, 3 moderate). The diagnostic performance of ultrasound was: sensitivity 77 % (74 % in 2011 and 80 % in 2012), specificity 99.8 %, positive predictive value 98.5 %, negative predictive value 97 %, accuracy 97.2 % (67 true positive; 668 true negative; 1 false positive; 20 false negative); 17 missed mild pneumothoraces were not immediately life-threatening (thickness less than 5 mm).

Conclusions Thoracic ultrasound (e-FAST) is a rapid and accurate first-line, bedside diagnostic modality for the diagnosis of pneumothorax in unstable patients with major chest trauma during the primary survey in the emergency room.

Keywords Thoracic ultrasound · Major trauma · Extended-FAST · Pneumothorax · Multidetector computed tomography

Introduction

Pneumothorax is a serious potential consequence of blunt thoracic trauma and, if misdiagnosed, it may quickly become life-threatening. For this reason, it requires an early diagnosis and urgent treatment [1]. Chest radiograph has been shown to be an insensitive examination. In a study of 225 trauma patients, Kirkpatrick et al. [2] found that antero-posterior supine chest radiograph had a sensitivity of only 20.9 % in the detection of pneumothorax if compared with computed tomography (CT), the current gold standard in this setting.

Thoracic ultrasound (US) has proved to be a promising tool [3], a bedside technique that can rapidly detect occult pneumothorax, hence avoiding serious potential consequences such as tension pneumothorax, especially in mechanically ventilated patients. In patients with major trauma, initial, first-line US examination is generally

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performed with a FAST (focused assessment with sonography for trauma) protocol able to depict intraperitoneal collections of free fluid that are an indirect sign of solid organ injury and require urgent surgical exploration [4]. After the initial FAST survey, the US examination may be extended to the thorax to rule out haemothorax and pneumothorax; when extended to the thorax this examination is known as extended-FAST (e-FAST).

In the trauma setting, the FAST examination is usually performed in hypotensive and haemodynamically unstable patients because it helps to determine whether immediate surgery is needed before the patient undergoes a CT evaluation; in fact, if intra-abdominal bleeding is present, the probability of death increases by about 1 % for every 3 min that elapses before surgical exploration [5]. In all unstable patients, in addition to the FAST acquisition, a right and left longitudinal anterior thoracic view could be quickly obtained to rule out pleural effusion and pneumothorax. Several authors [4–6] have investigated the accuracy of US for the detection of pneumothorax in trauma patients and in those subjected to interventional procedures such as lung biopsy. In a meta-analysis by Ding et al. [7] who compared the use of antero-posterior chest radiograph with transthoracic US for the diagnosis of pneumothorax, pooled sensitivity and specificity were 88 and 99 %, respectively, for US, and 52 and 100 % for chest radiograph.

The aim of this retrospective study was to assess, in our level-1 Trauma Centre, the diagnostic accuracy of thoracic US (e-FAST) in the rapid detection of traumatic pneumothorax in the emergency room in unstable patients with major trauma compared with CT scans and thoracostomy tube placement.

Materials and methods

Study protocol

This retrospective case series included 368 consecutive unstable patients admitted to our hospital's emergency department (a level-1 Trauma Centre) between January 2011 and December 2012 because of a major trauma [Injury Severity Scale (ISS) $\geq$ 15]. Patients were eligible for inclusion in the study if they had undergone, upon arrival in the emergency department, chest US as part of the e-FAST examination before the CT examination, the OR (Operating Room for Damage Control) and before the placement of a thoracostomy tube. All included patients were haemodynamically unstable major trauma patients (systolic blood pressure less than 90 mmHg). Institutional review board approval was obtained prior to commencement of this study.

The logistic organisation of our level-1 Trauma Centre (emergency room close to the CT room and operating room, staff radiologist present 24/24 h and readily available in the emergency room at the arrival of major trauma patients to perform bedside thoracic US) has allowed us to improve the use of bedside thoracic US in unstable patients.

All e-FAST examinations were performed by a staff radiologist of our department (with at least 6 years experience in clinical US and CT) at the bedside in the emergency room and recorded on videotape. Thoracic US was always performed and reported immediately after abdominal US during the primary survey and before the whole-body CT scans. Because of the need for immobilisation of trauma patients, thoracic US involves scanning only the anterior and lateral wall, not the posterior wall.

The presence of pneumothorax is determined on the basis of accepted sonographic criteria (disappearance of lung sliding and lung pulse, loss of B lines and identification of the lung point). We define mild, moderate or massive pneumothorax through the identification (with lateral scans) of the lung point on the parasternal line (mild), mid-clavicular line (moderate) or anterior/mid/posterior-axillary line (massive).

The CT images were interpreted by a staff radiologist without knowledge of the US findings. For every patient, we recorded the time of arrival at the emergency department, the time of e-FAST, and the time of multidetector CT (MDCT). The final US reports and images were reviewed by all authors in independent reading sessions (SI, VDG, BS, and VM) and compared with the MDCT images for verification; all images and reports were stored in our RIS/PACS system.

Technical equipment

In our institution e-FAST is performed at the bedside, with the patient in the supine position, using a portable US imaging unit (Esaote MyLab 75, Italy) and a 7.5-MHz linear probe. The linear high-frequency probe is suitable for visualisation of the pleural line; convex probes, working at lower frequencies (2–3.5 MHz), are indicated to evaluate the peritoneal cavity, pericardium, and lateral hemithoraces to detect haemothorax.

CT is performed with a 16-channel CT scanning unit (CT LightSpeed 16, GE Medical Systems, Milwaukee, WIS, USA). Intravenous contrast material (Visipaque 320 mg/ml, GE Medical Systems, Milwaukee, WIS, USA) is always employed for the evaluation of whole-body trauma. MDCT sections were obtained at a pitch of 1.5 and reconstructed to 2-mm-thick sections; mediastinal and lung windows were recorded on the PACS system.

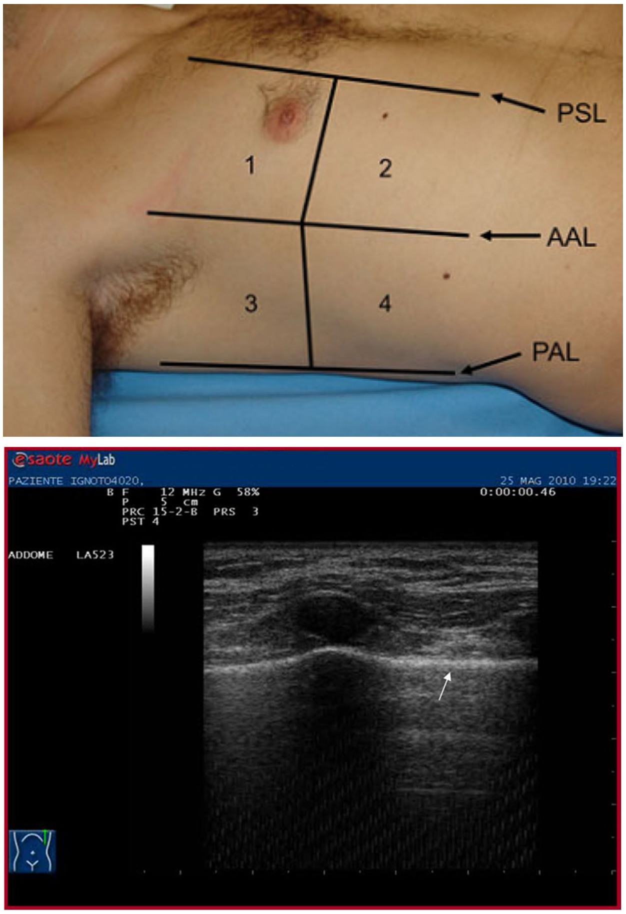

Fig. 1 Thoracic ultrasound: echogenic pleural line (*white arrow*); on *top*, *lines of US scans* (ParaSternalLine/AnteriorAxillarLine/PosteriorAxillarLine)

Sonographic semeiology

In a trauma setting, US evaluation for pneumothorax begins from the antero-inferior chest wall before moving to the lateral chest. When the probe is placed parallel to the long axis of the patient's body, we can visualise two adjacent ribs, producing a frank posterior shadow, and the echogenic pleural line in the corresponding intercostal space (Fig. 1). The pleural line represents either the parietal and visceral layers of the pleura in the normal subject and only the parietal pleura in cases of pneumothorax.

The basic sign that indicates normality is the presence of *lung sliding*, that is, a twinkling movement visible at the pleural line corresponding to the visceral pleura adhering to the parietal pleura. When pneumothorax occurs, the air between the two pleural layers causes abolition of the lung sliding so that the pleural line appears motionless. According to previous studies [8–10], the abolition of lung sliding does not necessarily confirm pneumothorax because other common conditions occurring in the critically ill cause disappearance of this sign (e.g. atelectasis). On the other hand, the visualisation of lung sliding on the antero-inferior chest wall in the supine patient has 100 % negative predictive value in the diagnosis of pneumothorax.

Another important sign we look for is the presence of *B lines*, which correspond to thickened interlobular septa in the interstitial syndromes such as pulmonary oedema and lung contusions [11]. B lines are comet-tail artefacts: they arise from the pleural line, spread up without fading to the edge of the screen and are synchronous with the respiratory movements. US detection of the comet-tail artefact allows pneumothorax to be discounted [12].

When lung sliding and B lines are absent in the antero-inferior chest area, thus suggesting pneumothorax, the sonologist should check the lateral-inferior chest wall looking for the *lung point*. This sign corresponds to a point where either lung sliding or B lines are visualised again because the lung adheres again to the parietal pleura. The lung point confirms the diagnosis of pneumothorax with a specificity of 100 % [13] and its location provides information about the extent and severity of pneumothorax [14].

In some cases, even if lung sliding is absent, the sonologist may note the presence of the *lung pulse*. This sign is a vertical movement of the pleural line that is synchronous to the heart beat and it is common in those conditions that cause a consolidated motionless lung (massive atelectasis and main-stem intubation) through which the heart movement is transmitted. Visualisation of lung pulse excludes the diagnosis of pneumothorax because the presence of the air in the pleural space does not allow the cardiac beat to be transmitted [8]. The diagnostic algorithm used to define a US diagnosis of pneumothorax is shown in Fig. 2.

Statistical analysis

Estimates of sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy were calculated for thoracic US, using MDCT as the reference standard for pneumothorax detection in all patients. In patients in whom US showed massive pneumothorax and a chest drainage tube was placed before CT, we considered escape or aspiration of intrapleural air at the time of drainage in the emergency room (as documented in the clinical record) to be the criterion suggestive of pneumothorax. Right and left lungs were considered separately for each patient (Figs. 3, 4).

Results

Between January 2011 and December 2012, a total of 720 consecutive major trauma patients (ISS $\geq$ 15) were

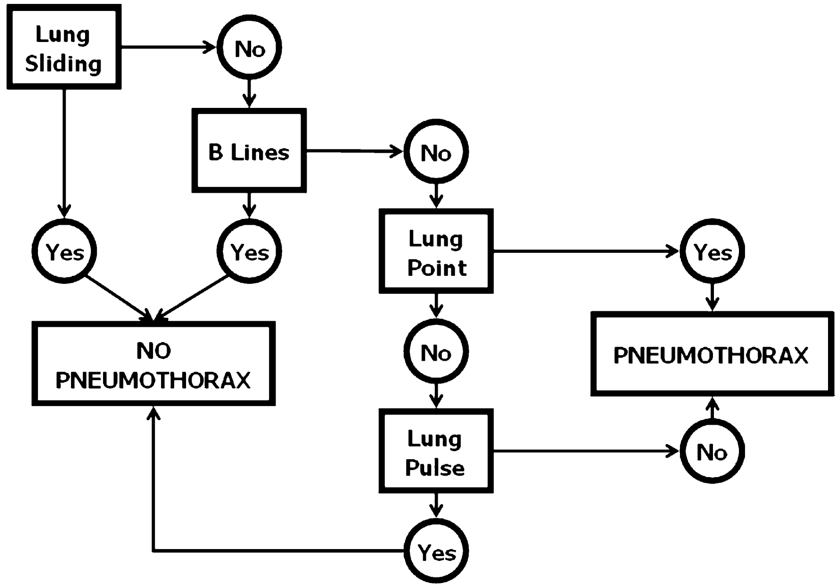

Fig. 2 The diagnostic algorithm used to define a sonographic diagnosis of pneumothorax (modified from Volpicelli et al. [15])

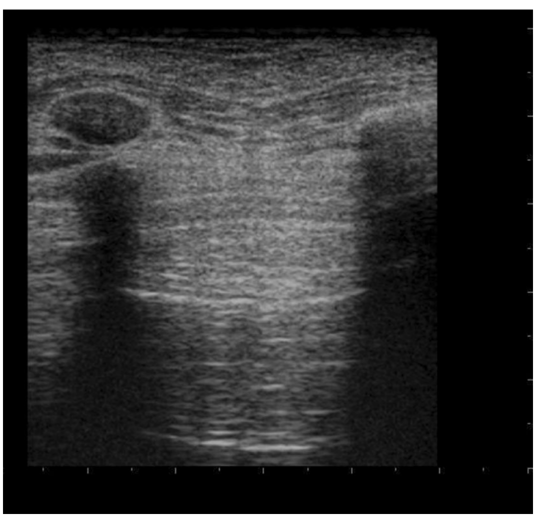

Fig. 3 Thoracic ultrasound, extended-focused assessment with sonography for trauma (e-FAST): mild left pneumothorax in a stabbed pregnant patient (24 years old); absent lung sliding and B lines

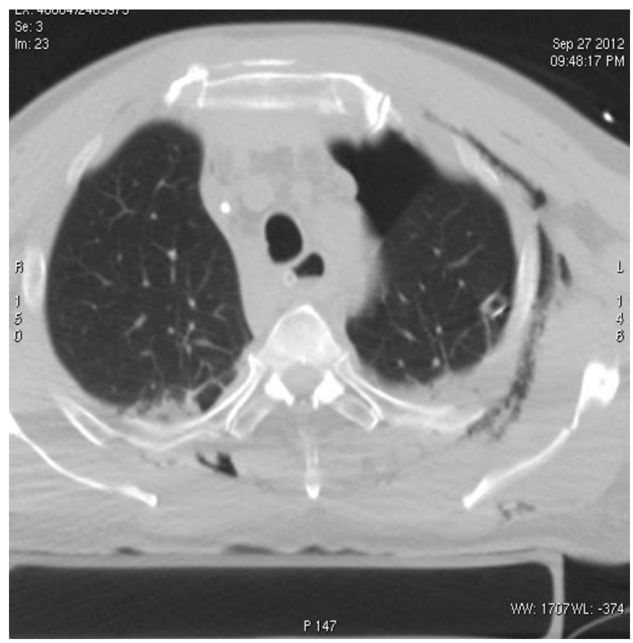

Fig. 4 Thoracic multidetector computed tomography (MDCT): confirmation of mild left pneumothorax in stabbed pregnant patient (24 years old); thoracic emphysema and haemothorax are also visible

admitted to our emergency department. Among these, 368 (273 men and 95 women; average age, 25 years; range, 16–68 years) haemodynamically unstable major trauma patients underwent e-FAST upon arrival in the emergency room (during the primary survey, 0–10 min after the patient's arrival) for the detection of pneumothorax, haemothorax and haemoperitoneum. Extended-FAST examination, followed by MDCT, was performed in all patients. In our level-1 Trauma Centre, all major trauma patients (ISS $\geq$ 15) undergo whole-body CT; this complete protocol has a significant advantageous impact on mortality (only 3 % within 24 h). These 368 patients, for a total of 736 hemithoraces, represent our study population.

The time interval between US and MDCT ranged 10–75 min, depending on clinical condition on arrival and the need for immediate measures for patient survival.

Among the 736 lungs in the 368 patients, chest US detected 67 pneumothoraces, while 87 pneumothoraces were either detected by MDCT or diagnosed based on the presence of air flush during thoracic decompression in the

Table 1 Extended (to thorax) values: preliminay results of emergency radiologist

Parameter	Thoracic ultrasound
Sensitivity (%)	**77** (67/87)
Sensitivity during 2011	**74.5 %** (38/51)
Sensitivity during 2012	**80.5 %** (29/36)
Specificity (%)	**99.8** (668/669)
False positive rate (%)	0.13 (1/736)
False negative rate (%)	2.7 (20/736)
Positive predictive value (%)	**98.5** (67/68)
Negative predictive value (%)	**97** (668/688)
Accuracy (%)	**97.2** (67 + 668/67 + 668 + 1+20)
Prevalence (%)	11.8 (87/736)

Data in parentheses are numbers of hemithoraces = 736/ pneumothoraces = 87

emergency room (5/87). Nine pneumothoraces were bilateral, 69 were unilateral. US missed 20/87 cases of pneumothorax; 17 of them were not immediately life threatening as they had a thickness less than 5 mm on CT. There was one false positive result in the diagnosis of pneumothorax by US: this was misdiagnosed in the apical region of the left lung in an emphysematous patient.

Defining the learning curve for thoracic US, all of the false negatives and the single false positive result occurred during the first five e-FAST examinations performed by each of the staff radiologists; 13/20 false negatives occurred during the first year (2011), and 7/20 during the second year (2012) of our experience. Therefore, the sensitivity of e-FAST for pneumothorax detection was 74.5 % during 2011 but 80.5 % during 2012 (668 true negative, negative predictive value 97 %). The specificity of e-FAST for pneumothorax detection was 99.8 % (67 true positive, positive predictive value 98.5 %). In the first 2 years of experience with chest US in our level-1 Trauma Centre (2011-2012), the overall diagnostic accuracy of this diagnostic tool for the diagnosis of pneumothorax in major trauma in the emergency room was 97.2 % (Table 1).

Discussion

Although MDCT has been considered the imaging modality of choice in patients with major trauma since the late 1990s, it is often used in conjunction with US for the urgent assessment of patients who have sustained major trauma, particularly in Europe.

Pneumothorax occurs in a large proportion of blunt thoracic traumas [1] and, even when mild, its detection carries a great clinical relevance because it may quickly progress to cause haemodynamic instability as a consequence of invasive ventilation. Bedside chest radiography is not very sensitive in the detection of traumatic pneumothoraces [2]. On the contrary, several studies have demonstrated that lung US has high sensitivity in diagnosing pneumothorax and that the location of the lung point in the supine patient allows evaluation of the extension of pneumothorax.

We have investigated, at our level-1 Trauma Centre, the use of thoracic US to rapidly detect pneumothorax during the initial resuscitation of unstable patients in the emergency room. In this setting, in fact, there are limited diagnostic options and even large pneumothoraces could be missed by either clinical examination or antero-posterior chest radiograph; every US diagnosis was compared with MDCT.

In the emergency department of our hospital, critically injured patients are resuscitated by a trauma team guided by a team leader. Patients suspected of having pneumothorax on physical examination undergo immediate tube or needle thoracostomy without awaiting imaging studies [16]; those patients were excluded from the present study. Patients not requiring immediate invasive intervention undergo a bedside US examination (e-FAST encompassing standard FAST and extended thoracic examination) performed immediately after the physical examination by a staff radiologist (operational 24 h/day). This is immediately followed by a whole-body MDCT examination if haemoperitoneum is absent; otherwise, if there is a suspicion of solid organ injury that requires urgent surgical exploration, the CT examination takes place immediately after surgery.

In our study, we evaluated the accuracy of e-FAST in the detection of pneumothorax using MDCT as the reference standard; in patients in whom US showed massive pneumothorax and a chest drainage tube was placed before CT, we used air flush at the time of chest drainage as a criterion to confirm the US diagnosis.

According to our results, e-FAST proved to be a rapid and useful test for the detection of pneumothorax, with an overall diagnostic accuracy of 97.2 %. Although our overall sensitivity was 77 %, if we analyse the 2 years separately, sensitivity was 74 % during 2011 and 80.5 % during 2012 (a good result for an initial experience with a new method). This sensitivity value is statistically significantly higher than that of supine chest radiograph (approximately 50 %, as reported in the literature). In addition, e-FAST is performed in only a few minutes, during the primary survey in the emergency room, and this is obviously a important factor to be taken into account compared with other chest US studies, not performed in the same complex conditions.

There was only one false positive result in the diagnosis of pneumothorax by chest US: this was misdiagnosed in the apical region of left lung in an emphysematous patient. In our study, no cases of significant subcutaneous emphysema caused false determination of the presence of pneumothorax. In our series, US missed 20/87 cases of pneumothorax: 13/20 of which were during the first year (maybe due to less specific experience); 17 of them were not immediately life-threatening as they had a thickness less than 5 mm on CT; 3/20 moderate pneumothoraces were missed in large habitus patients. Pneumothorax was bilateral in nine of our cases, but this fact did not affect the sensitivity of the e-FAST examination.

Some limitations to our study should be acknowledged. First, it was a retrospective study, so the US examinations were performed by different operators, with different levels of skill. All of the staff radiologists were at their first experience with thoracic US (though well-experienced in clinical US); nevertheless the diagnostic performance of e-FAST was high. A second limitation is that, because this was a retrospective study, we were unable to evaluate the accuracy of US in predicting the extension of pneumothorax in comparison with MDCT. As mentioned above, the location of the lung point in the supine patient allows one to predict pneumothorax extension. Even if there is no strict correlation between extension on the chest wall and the volume of intrapleural air, the extension of pneumothorax allows semiquantification of the volume, accurately discriminating between large and mild forms. This is enough to drive treatment decision making in most cases, even if the final decision depends on the clinical condition of the patient. During these first 2 years of experience at our level-1 Trauma Centre, we found that examining the chest with US can allow fast recognition (during the first 10 min of the “golden hour”) of the presence of pneumothorax with very good sensitivity and specificity, either in patients who undergo MDCT after US or who need immediate surgical exploration. In all cases, the team leader is informed about the presence of pneumothorax and the subsequent need to insert a chest drainage tube if he decides not to insert it immediately in the emergency room. Third, with regard to the value of the lung pulse, the sonographic diagnostic algorithm for pneumothorax detection is well codified; in all reports the lung pulse is the last criterion to be considered because in most cases “lung sliding + B lines + lung point” are sufficient to establish a confident diagnosis. In our study, only one patient had left-sided complete absence of “lung sliding + B lines + lung point” but the presence of lung pulse, due to right main-stem intubation with complete left atelectasis. We do not have sufficient data to discuss the impact of this sign.

Conclusions

According to our results, bedside thoracic US is a fast and helpful tool with very good accuracy in the workup of unstable major trauma patients, allowing a rapid and highly accurate diagnosis of pneumothorax. US does not require sophisticated equipment and it is readily available in the emergency department. In our emergency department, thoracic US is always used during the FAST examination in haemodynamically unstable patients, in who time sparing is crucial to allow an immediate treatment. We believe that thoracic US, allowing a fast and accurate diagnosis of pneumothorax, is an effective tool during the “golden hour”, and affects patient survival after a major trauma. A protocol limited to the antero-lateral chest wall is sufficient to definitely rule out pneumothorax because, in our series, CT analysis (with patients in the supine position) of occult pneumothorax showed that the anterior area was involved in almost all cases. E-FAST is cost-effective and repeatable, even when the clinical status of the patient changes. Therefore, more efforts are required to improve familiarity with thoracic US in critical care units and emergency departments.

Conflict of interest Stefania Ianniello, Vincenza Di Giacomo, Barbara Sessa, Vittorio Miele declare no conflict of interest.

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