Introduction

Maxillary sinusitis is a frequent complication in intubated patients undergoing mechanical ventilation.\(^1\) It is also a frequent cause of fever of unknown origin in intensive care unit (ICU) patients.\(^2\) In addition, maxillary sinusitis is frequently associated with ventilator-associated pneumonia (VAP) and severe sepsis.\(^1,3\) And it has been reported that the pathway and duration of endotracheal intubation were independent risk factors for maxillary sinusitis.\(^1\) Holzapfel et al.\(^1\) showed that the occurrence of VAP in patients undergoing prolonged mechanical ventilation can be prevented by the systematic search and treatment of nosocomial sinusitis. The classic treatment consists in the removal of nasal tubes, sinus lavage and intravenous antibiotics.\(^1,4\) In addition, the systematic application of nasal decongestant agents such as a combination of topically alpha-adrenergic agonists and corticosteroids seems to be effective in preventing nosocomial maxillary sinusitis in the ICU.\(^1\) The diagnosis of infectious maxillary sinusitis (IMS) is based on the isolation of organisms from a culture of purulent material obtained from the sinus cavities after the diagnosis of radiological maxillary sinusitis (RMS).\(^4,6\) RMS is defined by an air-fluid level or complete opacification of the maxillary sinus area.\(^7,8\) IMS is always associated with RMS and the IMS/RMS ratio is stable between studies.\(^1,4\) Indeed, 60 to 70% of the patients who have RMS really have IMS. But all patients with IMS have RMS.\(^1,4\) Therefore, as the first step in a clinical setting, the problem is to diagnose RMS.

RMS is not easily diagnosed in ICU. The “gold standard” for the diagnosis of RMS in ICU patients remains a computed tomography (CT) scan.\(^7,9\) However, CT scans suffer from significant limiting factors, including economic issues, availability and radiation. The most limiting factor affecting CT scans is the requirement of the transportation, with the additional risk for critically ill patients, to the radiology department.\(^10\) The reliability of the bedside use of the standard four-view sinus radiographic series is poor in ICU.
patients. Although B-mode ultrasonography has given good results compared with CT scans in this setting, there are still no reports about reproducibility. In addition, this technique requires specific technical skills. Sinuscopy allows for the diagnosis of infectious maxillary sinusitis (IMS) but this technique is invasive. Ultrasound has been suggested in the investigation of paranasal sinuses, especially because it is non-invasive and easy to perform at the bedside. B-mode ultrasound is interesting but requires an expensive ultrasound machine and expertise to interpret images.

A-mode is the simplest type of ultrasound. By contrast with B-mode, which is based on the principle of brightness modulation (represented by a grey scale), A-mode is based on the principle of amplitude modulation. A single transducer scans a line through the body with the echoes plotted on a screen as a function of depth. On the display, one axis represents the time required for the return of the echo, which corresponds to depth, and the other corresponds to the strength of the echo. A-mode ultrasound requires inexpensive equipment and seems easier to use than B-mode ultrasound. Moreover, it is a very fast procedure. Nowadays, A-mode is in widespread use in otolaryngology and ophthalmology. It is especially useful where a precise indication of the depths or relative reflectivities of echo-producing interfaces is required.

The aim of this study was to evaluate the efficacy by comparison with CT of bedside A-mode ultrasonography examination using an original 2.25 MHz 10 mm probe to diagnose maxillary sinusitis in mechanically ventilated patients.

Materials and methods

Study population
The study was performed in the surgical ICU of a university teaching hospital. French bioethical legislation did not require approval from the ethics committee for this type of study since it did not involve either physical or psychological considerations. Intubated and mechanically ventilated patients who required a head CT scan (for any reason) were included in this study. They were not included if radiological maxillary sinusitis had been diagnosed previously during their stay in the hospital.

Data collection
The following variables were recorded from patients: age, sex, New Simplified Acute Physiological Score (SAPS II), diagnosis upon admission, duration of intubation and length of stay in the intensive care unit when the CT scan was performed.

Study protocol
For each included patient, a bedside A-mode ultrasonography of the sinuses was performed on the same day as the head CT by an experienced staff intensivist blinded to the result of the CT scan. For the CT scan, RMS was defined as complete opacification or the presence of an air-fluid level higher than half of the sinus area, whatever the nature of the liquid. Absence of RMS was defined as an empty sinus, with an air-fluid level lower than half of the sinus area or mucosal thickening. The intensivist who performed the examination determined the result of the ultrasonography without any assistance and was blinded to the result of the CT scan. The duration of the A-mode ultrasound examination was recorded for each patient.

Data analysis
The number of patients necessary for the study was calculated on the basis of a preliminary study with
Sinus Explorer Evaluation

20 patients at the same ICU. Given an α risk of 0.05 and a confidence interval of 0.95, the number of patients to be included was 69 (138 sinuses).

We analysed the accuracy of A-Mode ultrasonography compared with CT scans for the diagnosis of RMS. A true positive (TP) result was defined as the presence of a positive A-mode ultrasound in a patient with an RMS according to CT. A true negative (TN) result was defined as the presence of a negative A-mode ultrasound in a patient with no RMS according to CT. A false positive (FP) result was defined as the presence of a positive A-mode ultrasound in a patient with no RMS according to CT. A false negative (FN) result was defined as the presence of a negative A-mode ultrasound in a patient with an RMS according to CT.

Standard formulae were used to calculate sensitivity (TP/[TP + FN]), specificity (TN/[TN + FP]), positive predictive value (TP/[TP + FP]), and negative predictive value (TN/[TN + FN]).

Results

Patients

Seventy patients were included and so one hundred and forty sinuses were examined. The characteristics of these 70 patients are given in Table 1.

Radiological maxillary sinusitis

The feasibility of A-mode ultrasonography was 100%. The duration of the examination was 117 ± 58 seconds per patient. The accuracy of A-mode ultrasound, compared with CT scan, for the diagnosis of radiological maxillary sinusitis is shown in Tables 2 and 3.

Table 1

Characteristics of the 70 patients at inclusion

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yrs</td>
<td>42 [33 – 58]</td>
</tr>
<tr>
<td>Male (%), female (%)</td>
<td>51 (73), 19 (27)</td>
</tr>
<tr>
<td>SAPS II score</td>
<td>43 [29 – 54]</td>
</tr>
<tr>
<td>Duration of intubation, days</td>
<td>4 [2 – 10]</td>
</tr>
<tr>
<td>Admission diagnosis</td>
<td></td>
</tr>
<tr>
<td>Cranial trauma, n</td>
<td>17</td>
</tr>
<tr>
<td>Polytrauma, n</td>
<td>16</td>
</tr>
<tr>
<td>Infection, n</td>
<td>4</td>
</tr>
<tr>
<td>Subarachnoid haemorrhage, n</td>
<td>17</td>
</tr>
<tr>
<td>Post-op, n</td>
<td>8</td>
</tr>
<tr>
<td>Other, n</td>
<td>8</td>
</tr>
</tbody>
</table>

SAPS II: new Simplified Acute Physiology Score16

a: Median [quartile 25% - quartile 75%]
b: at the time of the ultrasonography examination.
S. Boet et al.

Sensitivity, specificity, positive predictive value, and negative predictive value for A-mode ultrasound Sinus Explorer were 66.7%, 94.7%, 75.0% and 92.2% respectively. The incidence of RMS in our study was 19.3%. All (77/77) the empty sinuses were correctly identified as empty.

**Discussion**

Our results indicate that A-mode ultrasound may be a useful bedside method for ruling out the suspicion of maxillary sinusitis in mechanically ventilated patients. A-mode ultrasound with Sinus Explorer compared to CT Scan for the diagnosis of RMS has a sensitivity of 66.7%, specificity of 94.7%, positive predictive value of 75.0%, and negative predictive value of 92.2%. Several studies examining A-mode ultrasound and results have been controversial, with sensitivity and specificity ranging from 29% to 100% and from 55% to 99% respectively. These wide variations may result from several factors. The techniques may vary because of differences between probes, frequencies for scanning, sonographic norms and ultrasound devices.

To our knowledge, this is the first study evaluating a 2.25 MHz probe, which has different properties to the probes used previously (i.e. 3.5 MHz). Moreover, patient position is not always consistent in the other studies. Ideally, A-Mode ultrasound should be performed in an upright position. This was not possible in our population of ICU patients who were intubated and mechanically ventilated. This is also important because air behind the anterior wall of the sinus stops ultrasound. The sinus then appears to be empty. Westergren showed that the ultrasonographic diagnosis sensitivity improved when the examination was made in the semi-recumbent position. Only a few studies have used A-mode ultrasonography in critically ill patients but only one study compared A-mode with CT Scan in the diagnosis of RMS. Lucchin et al. reported sensitivity from 63% to 86% and specificity from 72% to 98% depending on the ultrasonographer. This wide range of values was related to the fact that ultrasonography results were divided into five categories, whereas we used only two categories (RMS or not) in our study, which is closer to the everyday practical question related to associated fever: "Is a sinuscopy required or not?" Nevertheless, our results are comparable to the Lucchin results, with moderate sensitivity and excellent specificity.

Our approach allowed us to identify more precisely which sinuses are not correctly interpreted with A-mode ultrasound. Firstly, mucosal thickening, which is not considered to be RMS, was positively identified by A-mode ultrasonography in 27.2%. Secondly, 44.4% of large effusions produced false negative ultrasonograph results. This is explained by the presence of air between the anterior wall and liquid, which stops ultrasound. Even using the semi-recumbent position, these cases were not well detected. This result was already described in our preliminary study. On the other hand, all the 77 empty sinuses in our study were identified by bedside A-mode ultrasonography as being

<table>
<thead>
<tr>
<th>A-mode device</th>
<th>CT scan</th>
<th>Absence of RMS</th>
<th>Presence of RMS</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Empty sinus</td>
<td>Mucosal thickening</td>
<td>Low air-fluid level</td>
<td>High air-fluid level</td>
</tr>
<tr>
<td>Absence of effusion</td>
<td>77</td>
<td>8</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td>Presence of effusion</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>77</td>
<td>11</td>
<td>25</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A-mode device</th>
<th>CT scan</th>
<th>Absence of RMS</th>
<th>Presence of RMS</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absence of effusion</td>
<td>Presence of effusion</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>A-mode device</td>
<td>107</td>
<td>9</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>Presence of effusion</td>
<td>6</td>
<td>18</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>113</td>
<td>27</td>
<td>140</td>
<td></td>
</tr>
</tbody>
</table>

Table 2

Results of A-mode ultrasonography device for RMS as a function of CT diagnosis items for 140 sinus examinations

Table 3

Results of A-mode ultrasonography device for RMS as a function of CT diagnosis for 140 sinus examinations
empty (100%). This is an interesting result in clinical practice for critically ill patients. If an intubated and mechanically ventilated patient is suspected of IMS, A-mode ultrasonography can minimise the need for transportation to CT, avoiding all the associated risks. This result indicates that A-mode ultrasound Sinus Explorer is useful for ruling out RMS diagnosis at the bedside in mechanically ventilated intensive care patients.

In our study population, the incidence of RMS was 19.3% and it is necessary to balance positive and negative predictive values with incidence value. Indeed, the higher the incidence, the higher the positive predictive value and the lower the negative predictive value. Likewise, the lower the incidence, the lower the positive predictive value and the higher the negative predictive value. This means that, with increasing RMS incidence (if A-mode ultrasonography is only in patients who are suspected of RMS), the negative predictive values will decrease and positive predictive values will increase. The rule for sensitivity and specificity is not the same since these values are independent of incidence. Therefore, even if our results were obtained in a general ICU population with patients who are not automatically suspected of RMS, the very high specificity (94.7%) justifies the hypothesis that A-mode Sinus Explorer is useful in patients when there is a specific suspicion of RMS (intubated and mechanically ventilated with fever and inflammatory syndrome).

The association between RMS and sepsis constitutes a strong suggestion of a diagnosis of IMS. Treatment for IMS relies on both a preventive approach, with the removal of all nasal tubes, and on a curative approach, with antibiotics and sinus lavage using Albertini’s drains.21

The rule is to ensure the vacuity of nasal cavities in order to prevent and treat IMS in ICU patients.2 Oro-tracheal and orogastric intubations are preferred to naso-tracheal and naso-gastric intubations.3 The removal of all nasal tubes associated with the semi-recumbent position is assumed to increase the permeability of the ostium and reduce the incidence of IMS.

For patients with IMS, the administration of parenteral antibiotics is usually prescribed.2 The efficacy of these antibiotics for sinonasal infections is unclear, and the long-term administration of parenteral antibiotics is associated with a moderate amount of morbidity. Souweine showed that intravenous antibiotherapy does not automatically result in an adequate concentration of antibiotics in the sinus mucosa.2 He also concluded that the frequent recovery of micro-organisms susceptible to the antimicrobial treatment administered suggests that systemic antibiotics may not be sufficient. This supports the choice of mupirocin (Bactropan) for topical application. Topical antibiotics are particularly effective in patients whose sinuses have been ‘opened’ to the nasal cavity. For patients with sinonasal infection with Methicillin-Resistant Staphylococcus Aureus (MRSA), treatment consists of a combination of oral and topical antibiotics (mupirocin) for 1–2 weeks.22 Additional, prospective studies are needed to quantify and contextualise the impact of sinonasal MRSA, as well as to provide a foundation for evidence-based treatment guidelines.

Our study has several limitations. First, only one experienced operator performed all the procedures and therefore we did not analyse either reproducibility with the device when used by other experts or the learning curve for novices. Secondly, although A-mode ultrasound appears to be inefficient for detecting pathology, it works well in the detection of normal sinuses. We did not evaluate the potential interest of a daily repetition of this fast procedure for the same patient. Daily ultrasonography sequences may improve the reliability of the A-mode ultrasonography and therefore minimise the need of risky transportation for CT scanning. Further studies should address ultrasonographic specificities, allowing for the radiological differentiation of IMS and pure RMS. These investigations may allow for a better understanding of the physiopathology and the more effective prevention of IMS.

**Conclusion**

In conclusion, the exploration of the maxillary sinuses in critically ill patients using the A-mode ultrasonography Sinus Explorer is a rapid, non-invasive, bedside examination using easily portable equipment, which should minimise referral to CT scan. Given its excellent specificity and negative predictive value, bedside A-mode ultrasound may be a useful first-line examination for mechanically ventilated ICU patients when maxillary sinusitis is suspected, and particularly for the elimination of a diagnosis of maxillary sinusitis.
Acknowledgments

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References