Mobile computerized tomography scanning in the neurosurgery intensive care unit: increase in patient safety and reduction of staff workload

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Object. Transportation of unstable neurosurgical patients involves risks that may lead to further deterioration and secondary brain injury from perturbations in physiological parameters. Mobile computerized tomography (CT) head scanning in the neurosurgery intensive care (NICU) is a new technique that minimizes the need to transport unstable patients. The authors have been using this device since June 1997 and have developed their own method of scanning such patients.

Methods. The scanning procedure and radiation safety measures are described. The complications that occurred in 89 patients during transportation and conventional head CT scanning at the Department of Radiology were studied prospectively. These complications were compared with the ones that occurred during mobile CT scanning in 50 patients in the NICU. The duration of the procedures was recorded, and an estimation of the staff workload was made. Two patient groups, defined as high- and medium-risk cases, were studied. Medical and/or technical complications occurred during conventional CT scanning in 25% and 20% of the patients in the high- and medium-risk groups, respectively. During mobile CT scanning complications occurred in 4.3% of the high-risk group and 0% of the medium-risk group. Mobile CT scanning also took significantly less time, and the estimated personnel cost was reduced.

Conclusions. Mobile CT scanning in the NICU is safe. It minimizes the risk of physiological deterioration and technical mishaps linked to intrahospital transport, which may aggravate secondary brain injury. The time that patients have to remain outside the controlled environment of the NICU is minimized, and the staff’s workload is decreased.

KEY WORDS • mobile computerized tomography scanning • neurosurgery intensive care unit • transport time

MANY patients in the NICU are critically ill and physiologically unstable. Head CT scanning is the most important morphological diagnostic procedure as a routine follow up during neurological deterioration or during a rise in ICP. Intrahospital transport to the CT suite of the Radiology Department involves risks of further deterioration from physiological instability or technical mishaps that may result in aggravated secondary injury to the brain.1,2,3 Furthermore, moving the patient out of the controlled environment of the NICU may result in great difficulties in pursuing adequate therapeutic interventions in the case of complicating events.

A mobile CT scanner has become available only recently, and experience with its use in neurointensive care is limited.1 In our NICU, a mobile CT scanner has been routinely used in almost 400 scanning procedures since June 1997. In this prospective report, we describe the scanning procedure, radiation levels and safety measures, estimations of staff workload, and an analysis of perturbations in clinical and technical parameters in groups of patients who were either transferred to the Radiology Department for conventional CT scanning or studied with the mobile CT scanner in the NICU.

Clinical Material and Methods

Equipment, Scanning Procedures, and Protective Measures

The mobile CT scanner (Tomoscan M; Philips Medical Systems, Eindhoven, The Netherlands) has previously been described in detail.1 One person can easily move the gantry, even in confined areas, and it can be positioned close to the patient’s bed. It has a translating function, making scanning possible with the patient resting on a nonmoving table or bed. In the NICU, patients are positioned with their head toward the center of the room with all monitoring equipment and the ventilator remaining wall mounted at their feet.

A fiberplastic board supporting a headrest is slid between the mattress and the bed frame and is secured with a bolt. The patient’s head is lifted onto the headrest and immobilized with elastic bands; the only precautions nec-
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ecessary are ensuring adequate lengths of ventilator and infusion pump tubing (Fig. 1 upper). The patient’s immobilized head is positioned in the gantry close to the isocenter by moving the scanner (Fig. 1 lower).

To protect the staff and other patients in the NICU from radiation exposure, mobile lead shields are used. One covers the gantry opening, and two shield the gantry along the patient’s sides. The neurosurgical nursing staff performs these preparatory procedures. The radiology assistants are responsible for checking the patient’s final position and performing the scanning. The resulting images can be directly compared with previous studies from the hospital’s digital x-ray archive on double computer screens at the NICU.

During transport to the Radiology Department for conventional CT scanning, the patients were monitored for raised ICP and standard cardiovascular and respiratory parameters. A mobile ventilator was used, and all infusion pumps were transported with the patient. The transport between the NICU and the CT suite in the Radiology Department requires approximately 6 minutes, including the use of one elevator.

Radiation Measurements at the NICU During Mobile CT Scanning

Measurements of the radiation doses, expressed as the CT DI, were performed using a centrally placed dosimeter in a head phantom. Radiation measurements were performed at various points in the room during scanning with a head phantom as a target. Dosimeters (thermoluminescence detectors) were placed in the rooms for a period of 1 month and were also carried by the staff.

Recording of Complications and Time Elapsed During Mobile and Conventional CT Scanning

During the first 5 months after installation of the mobile CT scanner in the NICU, it was only in use during regular office hours. There were also intervals when experienced staff was lacking, thus making mobile CT scanning impossible. This led to division of the NICU patients into two groups: those studied by mobile CT scanning and those undergoing conventional CT scanning at the Radiology Department.

The patients were categorized as high risk if they were physiologically unstable with cardiovascular instability, treated with 50% O₂ or more to reach normal PO₂ values, high ICP (≥ 20 mm Hg) or a combination of these factors. Medium-risk patients were categorized as physiologically stable and breathing with the aid of a respirator or having undergone placement of an intracranial catheter, or a combination of these factors. Low-risk patients were categorized as those who were physiologically stable, not using a respirator, and with no ICP measuring device. Only high- and medium-risk patients underwent scanning in the NICU during this period, whereas low-risk patients underwent CT scanning in the Radiology Department.

The protocol included registration of the number of infusion pumps, respirator treatment, and presence of intracranial catheters (intraventricular catheters, subdural drains, microdialysis catheters).

Time consumption, which was recorded for each scanning procedure, was defined as the time from the begin-

ning of the preparation for each procedure to its end, with all monitoring devices and the respirator reconnected and the patient back in bed.

Medical complications, defined as the occurrence of physiological instability, and all provoking events such as seizures, as well as technical mishaps, were recorded in both groups. Physiological instability was defined for ICP and cardiovascular and respiratory parameters as follows: an increase in ICP exceeding 5 mm Hg, a decrease or increase in systolic or mean blood pressure of more than 20 mm Hg, a decrease in O₂ saturation of more than 5%, bradycardia (< 50 beats per minute), tachycardia (> 120 beats per minute) and onset of a new arrhythmia (such as atrial fibrillation). Only changes sustained for at least five minutes were included. A technical mishap was defined as the occurrence of any unplanned event that potentially could have a detrimental effect on patient stability. Included are disconnection or malfunction of a device or any inadvertent manipulation that leads to extubation, for example.

Estimation of Staff Workload

The number of medical staff assisting the patient during transport or scanning was registered. The total time spent by the nursing staff on a single scanning procedure was calculated by multiplying the mean number of nurses and assistant nurses by the mean time for transportation and scanning.
mobile CT scanning, the complication rates were 4.3%.

During the study period, 50 mobile CT scanning procedures were performed in the NICU in 23 high- and 27 medium-risk patients. During the same period, 89 conventional CT scanning procedures, including 44 high- and 45 medium-risk patients from the NICU were performed in the Radiology Department. Table 1 shows a close similarity in the occurrence of complications during conventional CT scanning in both high- and medium-risk groups, except in extreme cases in which the physician is needed at the bedside because of the patient’s instability, and therefore their workload is also reduced.

### Statistical Analyses

Nominal values were compared with the two-tailed Fisher exact test. Continuous variables were compared with the two-tailed Mann–Whitney test and expressed as the means ± standard deviation if not otherwise indicated. Probability values less than 0.05 were considered significant.

### Results

#### Radiation Measurements

The CT DI of our mobile scanner was 34.4 mGy/100 mAs for the 120-kV x-ray spectrum, which is more than the two other scanners in the Radiology Department (CT DI values of 13.4 and 18.8 mGy/100 mAs), and is within 10 to 12% of the values stated by the manufacturer.

At a distance of 1 M from the isocenter through its horizontal plane, the dose was 1 μSv per scan for a 50-mA, 120-kV, 2-second scan, 5-mm slice thickness, and standard clinical settings. Staff working in the NICU environment received less than 0.05 mSv as recorded by the dosimeters during the 1-month study period.

#### Complications and Time Consumed

During the study period, 50 mobile CT scanning procedures were performed in the NICU in 23 high- and 27 medium-risk patients. During the same period, 89 conventional CT scanning procedures, including 44 high- and 45 medium-risk patients from the NICU were performed in the Radiology Department. Table 1 shows a close similarity between the groups with only the number of infusion pumps being significantly higher in the high-risk mobile CT group, compared with the high-risk conventional CT group.

There was a significant difference in the occurrence of complications during conventional CT scanning compared with mobile CT scanning in both high- and medium-risk groups (p < 0.05, Fig. 2). Medical complications or technical mishaps occurred during conventional CT scanning in 11 patients (25%) and nine patients (20%) in the high- and medium-risk groups, respectively. The different complications that occurred during the conventional CT scanning procedure are listed in Table 2. During mobile CT scanning, the complication rates were 4.3% (one patient) in the high-risk group and 0% in the medium-risk group. In the high-risk mobile CT group, one patient with subarachnoid hemorrhage who suffered renal failure and cardiovascular instability experienced a significant decrease in blood pressure that may have been provoked by the scanning procedure. The hypotension was reversed by intensified inotropic therapy. To date, this patient is the only one who has suffered a significant physiological disturbance in almost 400 mobile CT scanning procedures in the NICU.

As shown in Fig. 3, in high-risk patients, the mean time for mobile CT scanning in the NICU was 37 ± 12 minutes (range 20–60 minutes) compared with 79 ± 36 minutes for conventional CT scanning (range 20–225 minutes, p < 0.05). In medium-risk patients the mean time for mobile CT scanning in the NICU was 33 ± 13 minutes (range 10–60 minutes) compared with 55 ± 17 minutes for conventional CT scanning (range 20–105 minutes, p < 0.05).

#### Estimation of Staff Workload

During transport of high-risk patients, a mean of 1.3 nurses and 1.2 nurse assistants accompanied the patient, and a physician was often present also, at least during critical moments of the transport. During transport of medium-risk patients, a mean of one nurse and one nurse assistant accompanied the patient. Thus, the total time consumed for the nursing staff amounted to 198 minutes in high-risk cases and 110 minutes in medium-risk cases during conventional CT scanning. The estimated nursing time spent on mobile CT scanning in the NICU was 47 and 43 minutes for the high- and medium-risk patients, respectively, from which we infer a reduction in total nursing time of 145 minutes in the high-risk group and 64 minutes in the medium-risk group. These estimations are based on the assumption that one nurse is present during the entire mobile CT scanning procedure, and that the assistant nurses spend 10 minutes of their time on each scan. The radiology assistants, who usually are involved in moving the patient from the bed to the CT table and back during conventional CT scanning, do not do this during mobile CT scanning and therefore also spend less time on each procedure. The physicians in the NICU are not involved in the scanning procedure, except in extreme cases in which the physician is needed at the bedside because of the patient’s instability, and therefore their workload is also reduced.

### Table 1

Comparison of patients who underwent CCT scanning with those who underwent MCT scanning in the NICU*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High-Risk Patients</th>
<th>Medium-Risk Patients</th>
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<tbody>
<tr>
<td>no. of patients</td>
<td>44</td>
<td>45</td>
</tr>
<tr>
<td>respirator treatment (%)</td>
<td>23 (97.7)</td>
<td>27 (99.4)</td>
</tr>
<tr>
<td>intraventricular drain (%)</td>
<td>19 (82.6)</td>
<td>32 (88.9)</td>
</tr>
<tr>
<td>no. of drug infusion pumps (mean ± SD)</td>
<td>3.30 ± 1.94</td>
<td>1.57 ± 1.23</td>
</tr>
<tr>
<td>intraventricular drain (%)</td>
<td>4.46 ± 1.72†</td>
<td>2.07 ± 1.54</td>
</tr>
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* CCT = conventional CT; MCT = mobile CT; SD = standard deviation.
† p < 0.05.
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This study demonstrates that bedside mobile head CT scanning in the NICU environment is a safe method, minimizing episodes of physiological instability and technical mishaps linked with the transport of severely ill patients.

Multimodality monitoring of patients in the NICU can be divided into four levels, that is, 1) clinical examination; 2) morphological evaluation using CT scanning or magnetic resonance imaging; 3) on-line recording of physiological parameters; and 4) biochemical mapping in which routine blood and cerebrospinal fluid sampling are used, as well as microdialysis study of the tissue microenvironment. Information from all four levels should be integrated into any therapeutic decision. Morphological studies not only permit detection of surgically accessible lesions but also provide information that aids in the interpretation of ongoing physiological or biochemical changes. Because of the risks and complexity associated with the transport of severely ill patients, morphological evaluation tends to be kept to a minimum, usually being ordered when patients deteriorate, and important information may thus be lost. The availability of a mobile CT scanner in the NICU permits frequent bedside evaluation of intracranial morphological changes in vulnerable patients that may help us to understand their therapeutic needs before deterioration occurs.

Apart from better access to CT scanning, the prime advantage of the mobile system is the reduction in the risks of medical and technical complications associated with transport and scanning outside the NICU. This is now strongly confirmed by our results in almost 400 mobile CT scanning procedures in severely ill patients. The transport of patients from the ICU is known to increase the risk of physiological instability or technical mishaps that may aggravate secondary brain injury. In a study by Smith, et al.,9 technical mishaps similar to our observations were shown to occur in one third of 125 intrahospital transports from the ICU. Other studies have also documented deleterious alterations in physiological parameters during transport of neurosurgical as well as other unstable adult and pediatric patients, and transportation outside the ICU also increases the risk of ventilator-associated pneumonia.12–6,10 In cases of neurotrauma such complications are independent risk factors in determining the outcome.13 Leaving the controlled environment of the NICU also limits the possibilities for treating acute alterations in vital functions adequately. As a recent example from our experience, a patient’s tracheostomy tube was accidentally pulled out during elevator transportation, resulting in severe hypoxia for several minutes.

All unstable patients treated in the NICU are positioned with their heads pointing toward the center of the room. By this maneuver (change of position), mobile CT scanning can be performed in the patient’s own bed with minimum manipulation. This position has proved, somewhat surprisingly, to be superior to conventional positioning. Also in a more general perspective, it offers unrestricted access to the head and upper half of the torso and facilitates handling of intraventricular drains, microdialysis catheters, central venous lines, tracheal tubes, and so forth, as well as the general nursing of patients. We have noticed no practical difficulties related to the use of extra long tubing for ventilation.

Measurements of the radiation dose to which staff are exposed show low values, well below the Swedish reference limit value of 12.5 μSv/hour for persons performing radiological work. Patients, however, receive twice the radiation dose of conventional CT scanning. The image resolution of larger CT scanners is somewhat superior to the mobile system for the detection of subtle alterations in attenuation, but for ICU purposes this difference is outweighed by the advantages of low-risk, repeated scanning.

Costs in money, time, and staffing are considerable during CT scanning of ICU patients.5 The staff workload for one scanning procedure in which the mobile system was used was reduced by 60 to 75% in our study, depending on the patient’s risk level. By using two headrests, a second patient can be prepared for study during scanning of the first, and we have repeatedly been able to scan three patients in less than 1 hour. Because all preparatory work is done by the nursing staff in the NICU and the radiology assistants only participate briefly, in the final positioning and the actual scanning, mobile CT scanning also saves time and reduces the workload in the Radiology Department. Another obvious advantage for the Radiology Department is that the daily program of planned scanning procedures is left almost undisturbed by our having access to mobile CT scanning in the NICU. The economic con-

<table>
<thead>
<tr>
<th>Complication</th>
<th>High-Risk Transports</th>
<th>Medium-Risk Transports</th>
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</thead>
<tbody>
<tr>
<td>physiological changes</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>blood pressure</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>cardiac arrhythmias</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>decrease in O2 saturation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rise in ICP</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>seizures</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>respiratory arrest</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>technical mishaps</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>respirator-related mishaps</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>malfunction of infusion pumps</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>gastric tube pulled out</td>
<td>1</td>
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</tbody>
</table>

* Some of these complications occurred as a sequence of events or simultaneously in the same patient.

**FIG. 3.** Bar graph showing the mean time for transport and performance of conventional head CT scanning compared with mobile head CT scanning in the NICU in high- and medium-risk patients. The differences were significant (p < 0.05).
sequences of workload reduction may vary considerably between institutions, but cost reductions accompanying increased patient safety should follow, regardless of where the principle is applied.

The selection of patients for different study groups, that is, those studied by mobile CT scanning and those undergoing conventional CT scanning, is not entirely random. Problems facing night nursing and medical staff may be different and the use of the mobile CT scanner during regular office hours in this study could bias the results in its favor.

Conclusions

The mobile CT scanner is a new device that can be used safely for bedside scanning of the patient’s head while he/she remains in the NICU. The scanner virtually eliminates the need to transport unstable patients away from the controlled environment of the NICU and minimizes the risk of secondary injury to the brain caused by physiological deterioration or by technical mishaps during intrahospital transport. Bedside scanning in the NICU is also less time consuming, reduces staff workload, and has proved to be a useful tool in multimodality monitoring of severely ill neurosurgical patients.

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Disclosure

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References


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