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Continuous venovenous renal replacement therapy in critically ill patients: A work load analysis

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Summary
Objectives: To evaluate the nursing workload related to two techniques of continuous renal replacement therapy.
Research methodology: We analysed retrospectively the nursing work load caused directly by continuous renal replacement therapy in a cohort of patients admitted consecutively over 10 months. Two types of continuous renal replacement therapy have been compared: dialysis with regional citrate anticoagulation and haemodiafiltration with systemic heparin coagulation.
Setting: Academic Hospital Intensive Care Unit.
Main outcome measures: The nursing workload was defined by the time spent in the management of continuous renal replacement therapy, including preparation of the circuit and related biological controls.
Results: 60 patients underwent a total of 202 sessions of continuous renal replacement therapy. The nursing workload as expressed as % time of nursing care was similar (12.3 [9.4—18.8] vs 13.4 [11.7—17.0] %, for haemodiafiltration and dialysis respectively, $P = 0.06$). However, the distribution of the nursing workload is different: the bigger proportion of care is circuit preparation in haemodiafiltration and biology control in dialysis.
Conclusions: Nursing time dedicated to continuous renal replacement therapy is similar whatever the renal replacement therapy technique. However, a longer duration of the filter and a better circuit predictability with dialysis and citrate anticoagulation are potential benefits for nursing workload.

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Implications for Clinical Practice

- Few studies have addressed the issue of nursing workload related to continuous venovenous replacement therapy (CRRT) in ICU.
- The study shows that CRRT requires nursing care for less than 15% of the dialysis time whatever the technique used, continuous veno-venous haemodiafiltration with systemic anticoagulation with heparin (CVVHDF) or continuous veno-venous haemodialysis with regional citrate anticoagulation (CVVHD).
- However the techniques are not equal. CVVHDF is associated with repetitive and unpredictable circuit changes, which represent a mean 90 minutes dialysis break, and disruption in the nursing plan. CVVHD requires more time dedicated to biological controls but is more predictable with less dialysis break than CVVHDF.
- Therefore, the technique chosen for CRRT has a significant impact on nursing workload.

Introduction

The load of nursing care is one of the elements that contribute to patients outcome in the Intensive care Unit (ICU) and would influence the prognosis (Kelly et al., 2014). We know that a high patient/nurse ratio impacts on safety and may even increase mortality in ICU (Penoyer, 2010), as it has been demonstrated in more routine care (Aiken et al., 2002; Needleman et al., 2002, 2011). The subject is still debated (Moreno et al., 2009), but it seems well established that a heavy nursing workload is source of complication and expense, especially after surgery (Amaravadi et al., 2000).

Little attention has been paid in the literature to the nursing workload in the management of renal replacement therapy (CRRT) in critically ill patients (Miranda et al., 2003). CRRT is frequently used in ICU, takes time to nurses and decreases nurses' availability to other treatments. A new anticoagulation technique of dialysis circuit appeared in the early 2000s that requires in regional anticoagulation with citrate (Palsson and Niles, 1999). Citrate regional anticoagulation extends the circuit lifespan and reduces costs when compared to a circuit anticoagulated with unfractionated heparin (Korkeila et al., 2000; Oudemans-van Straaten et al., 2009; Schilder et al., 2014; Zhang and Hongying, 2012). Indeed, regional citrate anticoagulation reduces the risk of bleeding, a significant advantage after cardiac surgery (Morabito et al., 2012). Consequently, it allows a simpler management by avoiding untimely dialysis breakdown. However, it interferes with calcium metabolism and alters the acid—base balance; therefore the use of citrate imposes more constraints in terms of biological monitoring (Hetzel et al., 2011).

Two years after the implementation of regional citrate anticoagulation technique in our ICU, a sufficient period to develop expertise within the team, we noticed several differences in the nursing care of the CRRT between the two anticoagulation techniques (systemic heparin and regional citrate). We have therefore designed a retrospective observational study in order to compare the nursing workload of the two techniques. We have precisely defined the nursing workload related to dialysis and have observed its distribution from a cohort of consecutive patients in a post cardiothoracic surgical ICU.

Methods

This is an observational study of all CRRT sessions performed in the cardiothoracic surgical ICU of University Hospital of Montpellier between June 2012 and February 2013.

Definitions

Definition of continuous renal replacement therapy (CRRT) session

The session was defined as any CRRT for a minimum of 24 hours and maximum 72 hours in accordance with regulatory condition use of the circuits. For each session, a CRRT file was opened as soon as the renal replacement therapy indication was decided, where all the data for the session, including all the interventions required by CRRT management, were collected. The nurse in charge of the patient completed the file. After disconnection, the nurse recorded the alarm history, the treatment time and filter duration provided by the CRRT machine.

A new file was started (even if it was the same patient) unless the session was interrupted within the first 24 hours. In this case, we considered this the same session.

Continuous renal replacement therapy techniques

The CRRT routinely used in the unit was either a continuous veno-venous haemodialysis (CVVHD), or continuous veno-venous haemofiltration (CVVHDF) with the same type of machine (Multifiltrate, Fresenius Medical Care, Bad Homburg, Germany). The design of the CRRT machine allowed use of regional anticoagulation with citrate for CVVHD, but not for CVVHDF where unfractionated heparin was used intravenously.

Anticoagulation with heparin was prescribed to ensure effective systemic anticoagulation, usually 1.5—2 times the reference (aPTT 50—60 s). Each dose change was reviewed after six hours and at least once daily. For regional citrate anticoagulation, the protocol followed was the one recommended by the circuit and solutes provider (Fresenius Medical Care). A solution of trisodium citrate 4% was administered continuously by a specific pre-dilution pump coupled to the blood flow rate to obtain a constant citrate plasma

Table 1 Tasks included in the calculation of nursing dialysis workload.

	CVVHDF		CVVHD
Circuit preparation	37 [31–39]		35 [32–43]
Connection		20 [15–26]	
Dialysate solution preparation	5.9 [3.6–7.9]		2.5 [2.3–3.3]
Compensation solution preparation	NA		2.1 [1.7–2.6]
Calcium solution preparation	5.3 [4.0–5.5]		NA
Unfractionated heparin (UFH) preparation	NA		2.0 [1.9–1.1]
UFH change	NA		3.2 [3.2–30.2]
Biological test preparation	2.0 [1.7–2.1]		2.4 [2.3–2.7]
Blood collection for biological test	17 [15–20]		6.5 [6.3–6.9]
Dialysate solution change	3.0 [2.9–3.0]		1.6 [1.5–1.6]
Compensation solution change	NA		1.5 [1.4–1.6]
Ultrafiltration collection bag change		1.5 [1.4–1.8]	
Calcium solution change	1.1 [1.0–1.3]		NA
Citrate solution change	0.9 [0.8–1.1]		NA
Alarm or warning		0.9 [0.8–1.0]	
Flow rate changes (blood, citrate or calcium pump)		0.53 [0.48–0.57]	
Circuit disconnection and removal		21 [19–23]	

Values are expressed in minutes, median [25;75 percentile].
CVVHDF: continuous veno-venous haemodiafiltration with systemic anticoagulation with unfractionated heparin; CVVHD: continuous veno-venous haemodialysis with regional citrate anticoagulation.

concentration of 4 mmol/L, sufficient to lower Ca^{++} concentration in the extracorporeal circuit to prevent coagulation. A Ca^{++} solution provided by an independent post-dilution pump restored postfilter Ca^{++} concentration. Repeated sampling every 6–8 hours were required to adjust the dose of citrate and calcium solutions.

The two forms of CRRT differed in both anticoagulation and treatment mode. In the case of the CVVHD, it was exclusively dialysis without haemofiltration. The average dose of dialysis (dialysate volume per hour) was set at approximately 25–30 ml/kg/h, and blood pump flow adjusted to three times the dialysis dose. In CVVHDF, it was a combination of dialysis and haemofiltration. The average dose of dialysis (dialysate volume per hour plus volume restitution per hour) was set at approximately 30–40 ml/kg/h, and blood pump flow adjusted to keep a filtration fraction below 15%. The ultrafiltration compensation solution was administered mostly in post-dilution.

Definition of the nursing dialysis workload

The nursing workload related to CRRT care (or nursing dialysis workload, NDW) was defined by the sum of the time spent on each intervention in the context of the CRRT management (Table 1). To calculate these times, each task was identified, recorded and timed (up to five times with various nurses and patients, at different times of the day or places in order to get a representative average time). Preparation time, which included the installation time, the connection and disconnection of the circuit, was distinguished from the time dedicated to the treatment itself. The time spent for the blood tests included the different handling times (from preparation to blood collection and included measures with a point-of-care analyser). Time spent on managing anticoagulation included, for regional citrate, blood tests and adaptation of calcium or citrate administration (preparation and changes of calcium or citrate solution, changes of calcium or citrate flow rates), and for heparin, the adaptation of heparin doses (preparation and changes of dose). The incidents that triggered an alarm (alarms or warnings) involving interventions by the nurse were those listed by the machine.

Patient selection

All adult patients admitted consecutively in the ICU, who required CRRT, were included in the study. The indication and CRRT type were left to the physician's discretion, with a prime indication for CVVHD, except in cases of severe metabolic disturbances requiring more rapid treatment (hyperkalemia, severe metabolic acidosis) or citrate accumulation with CVVHD where CVVHDF was preferred.

Care organisation

The ICU has 15 beds with a ratio of 2 nurses for 5 patients. ICU patients are not in single rooms; there are three rooms of two beds, two rooms of four beds and one room with one bed. A space is dedicated to the treatment of blood gases with a point-of-care blood gas analyser for dosing ionised calcium. The point-of-care machine was also used for patients who were operated on in the five surgical rooms adjoining the ICU.

Data collection

A database included the dialysis records information. The files were checked and updated where required by a research nurse, who was not involved in the patient care,

Table 2 Continuous renal replacement therapy session times.

	CVVHDF	CVVHD	*P*
CRRT session time (h)	37 [25—53]	69 [43—74]	<0.001
Filter duration (h)	35 [23—52]	65 [35—72]	<0.001
Treatment time (h)	30 [19—46]	60 [37—68]	<0.001
Filter duration/treatment time (%)	91.9 [89.7—93.8]	94.4 [91.2—95.8]	0.002

Values are expressed in median [25;75 percentile].
CRRT: continuous renal replacement therapy; CVVHDF: continuous veno-venous haemodiafiltration with systemic anticoagulation with unfractionated heparin; CVVHD: continuous veno-venous haemodialysis with regional citrate anticoagulation; CRRT session time: from circuit preparation to its removal at the end of the session; filter duration: from set up to stop, including treatment time, and treatment interruption like for solution changes or alarms; treatment time: time of effective CCRT.

before collecting the data in the database, in order to limit the number of missing values.

The patients main demographic characteristics and relevant medical information for the dialysis were recorded, as well as those on dialysis management including medical prescriptions (blood pump flow, dialysate and compensation solution flows, patient's weight loss per hour), all nursing supervision elements (circuit pressures, weight loss, etc.), the frequency of blood tests, all tasks needed for the implementation and management of CRRT, the circumstances of withdrawal and alarm management. The treatment time (actual time spent on CRRT) and filter duration (from the circuit preparation to its disconnection, including CRRT duration, treatment interruptions such as changes of solution, alarms, etc.) were provided by the CRRT machine and were also recorded.

From this database, nursing interventions for the management of CRRT were extracted and to the average duration applied as reported in Table 1.

Statistical analysis

For statistical analysis, SPSS software program (Version SigmatStat 3.0; SPSS Inc., San Jose, CA, USA) and XLSTAT (version 2011.3.01; Addinsoft, Paris, France) was used. Normality distribution was assessed by a Kolmonorov—Smirnov test.

Most variables showed deviation from normality and were analysed with nonparametric tests (Mann—Whitney or Wilcoxon tests). A few variables demonstrated a normal distribution and were analysed with Student's *t* tests, but all data are expressed as medians [25th—75th percentiles]. A Fisher's exact test was performed to analyse proportions and rates. Statistical significance was assumed if *P* value $\leq$0.05.

Results

Population

Sixty patients were treated with CRRT and underwent 1—19 (2 [1—5]) sessions: 167 CVVHD and 35 CVVHDF. Sixteen patients (27%) were treated with both techniques.

Session characteristics

CRRT sessions were longer in CVVDH than in CVVHDF, with filter and treatment durations significantly longer in CVVHD (Table 2); 31% of CVVHDF and 67% of CVVHD sessions were greater than 48 hours in duration.

The ratio between treatment time and filter duration, which expresses the percentage of filter time spent on CRRT, was significantly higher in the CVVHD group (Table 2).

Nursing dialysis workload (NDW)

By session, the NDW was significantly greater in CVVHD. However, since the CVVHD sessions were longer, the NDW related to the total duration of the session was similar in the two techniques (Table 3).

Both techniques differed by the workload distribution: in CVVHDF, circuit preparation represented the largest percentage of the NDW, while in CVVHD, it was the management of the blood tests (Table 4).

The proportion of time spent on the preparation was twice that of CVVHDF than in CVVHD. On the other hand, the

Table 3 Nursing dialysis workload.

	CVVHDF	CVVHD	*P*
Global NDW (min)/CRRT session	304 [235—373]	497 [401—591]	<0.001
NDW/CRRT session time (%)	12.3 [9.4—18.8]	13.4 [11.7—17.0]	0.06

Values are expressed in median [25;75 percentile].
CRRT: continuous renal replacement therapy; CVVHDF: continuous veno-venous haemodiafiltration with systemic anticoagulation with unfractionated heparin; CVVHD: continuous veno-venous haemodialysis with regional citrate anticoagulation; NDW: nursing dialysis workload.
NDW/CRRT session time: proportion of NDW by CRRT session.

Table 4 Details on nursing dialysis workload.

Nursing dialysis workload	CVVHDF	CVVHD	P
Preparation	37.9 [31.0—45.0]	20.1 [17.6—26.9]	<0.001
Blood tests	14.7 [11.6—21.1]	35.9 [26.7—40.9]	<0.001
CRRT management	21.3 [12.9—29.6]	17.9 [12.7—21.1]	0.013
Anticoagulation management	2.6 [0.8—3.9]	7.1 [5.7—8.3]	<0.001
Incident management	14.3 [6.8—65.2]	15.4 [9.3—23.8]	0.264

Values are expressed in % of DNC, median [25;75 percentile].
CRRT: continuous renal replacement therapy; CVVHDF: continuous veno-venous haemodiafiltration with systemic anticoagulation with unfractionated heparin; CVVHD: continuous veno-venous haemodialysis with regional citrate anticoagulation; preparation: the installation time, the connection and disconnection of the circuit; blood tests: time dedicated to biological controls from preparation to blood collection and measurement; CRRT management: time dedicated to solution or flow rate changes; anticoagulation management: treatment adaptation for CVVHDF or CVVHD; incident management: any warning that required nurse intervention.

NDW related to time spent completing blood tests was more than twice the time in CVVHD than in CVVHDF (Table 4). The NDW per hour of dialysis was thus higher in CVVHD than in CVVHDF (7.5 [6.4—9.6] vs 4.9 minutes [4.0—7.6] minutes, $P < 0.001$).

In the time devoted to blood tests, management of anticoagulation was three times longer in CVVHD than in CVVHDF, but represented less than 10% of the NDW. Conversely, CRRT management itself, including changes in solution and treatment, was greater in CVVHDF than in CVVHD (Table 4).

The percentage of NDW time used to manage the incidents was similar between the two groups (Table 4).

Discussion

Our study demonstrates that the percentage of time spent by the nurse on CRRT with CVVHDF vs CVVHD is similar, around 13% of CRRT time. This means that the nurse must dedicate approximately eight minutes per hour; inversely, this means also that renal replacement therapy is ensured automatically, thanks to the machine technology, for more than 85% of the CRRT time. Therefore, nurses can spend most of their working time on other patient care. However, the distribution of NDW is very different from one technique to another, very concentrated around the repetitive connection and reconnection of the circuits for CVVHDF, and more regularly distributed on biological controls for CVVHD.

Indeed, for CVVHDF, the preparation time represents the greater part of nursing time, over a third for a CRRT session (37.9%). This is due to the shorter duration of the sessions, a small proportion of CVVHDF reaching 72 hours (only 31% last more than 48 hours). In CVVHD, a large proportion (35.9%) of nursing time is dedicated to biological controls, including monitoring anticoagulation with citrate. However, the CVVHD sessions are long enough to space out the times dedicated to the preparation, the connection and the reconnection of the circuits (67% of the sessions last longer than 48 hours).

The time duration of CVVHDF circuits observed in our study, around 30 hours, is very comparable to the duration observed in other studies (Korkeila et al., 2000; Zhang and Hongying, 2012; Morabito et al., 2012; Schilder et al., 2014). In these studies, the filter time in CVVHD is significantly longer than in CVVHDF (1.5× longer); it is even better in our study (2× longer). These results confirm that regional citrate anticoagulation increases the lifespan of the CRRT circuit, but the originality of this work is to show that the circuit duration difference has an impact on NDW.

In CVVHDF, the repeated disconnection—reconnection process, which represents the bulk of nursing time spent on CRRT, is ineffective and incompressible, that means that this time is lost for the treatment per se. With circuit anticoagulated with citrate, nursing time is mostly devoted to biological controls, which does not interfere with the prescribed dialysis dose. Moreover, circuit failure prompts dialysis circuit changes, which is often unpredictable and prolonged (average of 90 minutes of treatment interruption). In CVVHD, the time used for each biological control of citrate anticoagulation is short (about 20 minutes), and easy to integrate into the NDW without losing the dialysis efficiency (no break in the treatment). An inadvertent shutdown of the circuit is a source of care disruption. The nurse is then forced to deal exclusively with the refitting of CRRT in order to respect the prescribed dialysis dose, possibly at the expense of other care activities.

If CVVHD has a more important metabolic constraint, imposing regular monitoring with repeated blood tests (Hetzel et al., 2011), has certain advantages in terms of morbidity with less bleeding or need for transfusion, and possibly reduced mortality, regardless of the nursing workload (Korkeila et al., 2000; Oudemans-van Straaten et al., 2009; Zhang and Hongying, 2012). Yet, the nursing workload is known to impact itself morbidity and mortality in ICU (Aiken et al., 2002; Needleman et al., 2011; Penoyer, 2010). In the case of CRRT, the influence of the technique used on the nurse management had not been specifically studied yet.

This work suggests that, though the two techniques are quantitatively equivalent in hourly nursing work, they are very different qualitatively. In addition to patient/nurse ratio, the nature of care influences the quality of the care (Amaravadi et al., 2000; Needleman et al., 2002); in this case, the nurse activity in CVVHD seems more directly dedicated to guarantee the performance of CRRT. While the benefit of continuous over intermittent RRT is not definitively established in ICU (Bagshaw et al., 2008; Schefold et al., 2014; Vinsonneau et al., 2006), CRRT seems nevertheless more suitable for patients with cardiovascular unstable condition, where fine control of the hydro-electrolytic balance and volume is required. Here the importance of respect for the dialysis dose target is essential (Ronco et al., 2000), which seems to give a substantial advantage to citrate anticoagulated circuit compared to heparin anticoagulated circuit. For the latter, in addition to the dialysis treatment time ''lost'' for the patient, repeating handling for connection and disconnection exposes with an increased risk of infection from the dialysis catheter.

However, indications for the two techniques, haemodiafiltration or dialysis alone, are different. As in this work, the use of CVVHDF may be preferred when a high dose of dialysis is considered necessary or urgent by the prescriber. It has been shown that the addition of a dialysis dose increased the performance of the CRRT or improved life expectancy (Ronco et al., 2000; Saudan et al., 2006). It appears in our practice that the goal of short-term performance has motivated the use of the CVVHDF. However, CVVHDF performance may be questioned due to inadvertent shutdown of the circuit. The preference of CVVHD, besides the argument of a better use of nursing time, could be the treatment efficacy. It would probably be desirable to compare the actual effectiveness and costs of these two CRRT techniques by integrating the dimension of the NDW (Schilder et al., 2014).

The limitations of the study are numerous:

- This is a single-centre study, where the architectural organisation and patient/nurse ratio, which is in the range of the national regulatory standard, are specific. Nevertheless, it is unlikely that these elements have a significant influence on the nursing time distribution.
- The proportion of patients treated by haemodiafiltration is low when compared to patients treated with the citrate dialysis, but the two techniques are widely used in this unit and teams are well trained to them.
- An evaluation of the effectiveness of the two forms of CRRT is beyond the scope of the study.
- Due to the complexity of variables involved in patient outcomes, these are not considered.
- In this study patients were prescribed CVVHDF in case of severe metabolic disturbance, and post-dilution was predominantly used.

Conclusion

The NDW is similar between the two techniques when global workload is considered, but differs qualitatively. The citrate anticoagulation requires a more intense biological monitoring but the duration of the filters and the good predictability over time, are beneficial to ensure the prescribed dialysis dose. Furthermore, the number of biological controls may be probably reduced in stable conditions, allowing a substantial reduction in workload, but further studies are required to assess the safety of such a strategy.

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Conflict of interest

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