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Dyskalemia: a management problem for students

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Abstract

Background: Although dyskalemia is common, its management can be problematic for students and general practitioners, especially when it occurs in patients with heart and renal failure. The basic academic knowledge of general medicine students, who have often not yet encountered clinical situations of dyskalemia, remains unclear in this regard.

Objectives: The purpose of this study was to evaluate the knowledge and reflexive practices of general medicine students in regard to dyskalemia.

Methods: A cross-sectional survey, based on a self-questionnaire, of all of the students enrolled in general medicine studies at the Faculty of Medicine at the University of Nancy (France) at the end of their degree. The students were asked questions pertaining to specific

clinical situations. The answers were compared to the information provided in the medical curriculum as well as to the relevant European guidelines.

Results: We collected 290 of the questionnaires (participation rate: 81.2%). The hyper- and hypo-kalemia thresholds considered pathological (3.5-5.0 mmol/L) were known by 78% and 67% of the students, respectively. The perception of danger in case of severe hypokalemia was underestimated by 62.7% of them. In most cases, the proposed management of hyperkalemia in heart and renal failure did not comply with the relevant guidelines. The students tended to favor permanent discontinuation of the administration of converting enzyme inhibitors (ACE) and/or mineralocorticoid receptor antagonists (MRA) without considering the need for their reintroduction (51.6%). Sodium polystyrene sulfate was frequently seen as an appropriate first-line treatment for hyperkalemia (45%).

Conclusions: The knowledge and competence of general medicine students appear to be lacking for hyperkalemia in heart and renal failure, and they are long way from full compliance with the relevant European guidelines. Exposure to complex clinical situations as part of the medical curriculum, therefore, seems essential to improve the way dyskalemia is managed in France.

Strengths and limitations of this study

1) The main strength of this study lies with the use of an open-ended questionnaire, which ensured that there were no leading questions and not suggest possible answers to the situations described.
2) The second strength: The questionnaires were filled out in the presence of a friendly and neutral team, without direct intervention but with immediate availability of assistance if required (self-administered questionnaire).
3) The third strength: Methodological bias was minimized by providing resources to organize the task of collecting, analyzing, and processing the information.
4) The first limitation: Sample selection bias cannot be fully ruled out, although we are confident that we were able to ensure adequate representativity of the population of students enrolled in French general medicine studies.
5) The second limitation: we cannot exclude that the respondents were the most motivated students, however we had a high response rate of over 81%.

1. Background

Dyskalemia (hypokalemia and hyperkalemia) are potentially dangerous conditions (1,2). It is mostly encountered in high-risk patients (e.g., with heart failure, renal failure, cardio-renal syndrome, diabetes, hypertension) but also, occasionally and unexpectedly, people without comorbidities (3). Management is not consensual according to the guidelines in place, and the thresholds for hypokalemia and hyperkalemia are not universal (4).

Many studies of patients with heart failure have focused on the association between blockers of the renin-angiotensin-aldosterone system (RAAS) and anti-aldosterone, as all may trigger hyperkalemia and can be a source of problems, particularly for general practitioners (5-8). In contrast, loop diuretics may lead to hypokalemia or dehydration, which can be difficult to manage in the context of renal insufficiency (9).

It is not precisely known how general practitioners deal with dyskalemia, especially as there is not a specific decision tree to guide them in this regard. While the way they go about this is presumably based on their prior experiences and on interactions with other specialists, the basic academic knowledge and skills of general medicine students who have not yet encountered clinical situations of dyskalemia remains largely unknown.

2. Methods

2.1. Objectives

The main objective of this study was to evaluate the knowledge of French general medicine students regarding dyskalemia.

The secondary objective was to evaluate how they manage clinical situations involving dyskalemia.

2.2. Type of study

All of the students (from the first to the third year of study) at the end of their general medical studies in Nancy, France, (N=357) were asked to answer a self-questionnaire, kind of like

Durieu et al, regarding the perception of adverse drug reactions (10) during their final exams in June 2017. The questionnaire was in two parts: the first two questions focused on the perception of dyskalemia and the next three questions were clinical situations with open answers, to avoid influencing the answers. The questionnaire was constructed in such a way that the study reflects a general medicine context, where more information is not available at the start usually limited to the only information available in the medical report. The objective was to evaluate the student's "reflex" management without suggesting a list of predefined answers so as not to influence the student. The answer was open-ended.

The questionnaire was first tested with ten students to ensure that it was fully understood in the first round and that the answers were stable in the second round, as well as to ensure the validity of the questionnaire (11).

The results were analyzed by collecting the terms in verbatim form. Thus, "monitoring under scope", "intravenous hydration", and "calcium gluconate" were classified under the term "hospitalization/emergency" as these treatments are not available in the public health care system; "taking vital signs" and "blood pressure measurement" were classified under "assessment/clinical examination". The analysis and classification of the verbatim statements were performed after comparing the independent analyses of two authors (S. L. and B. J.M.) followed by arbitration.

The answers were then compared to the treatment stipulated in the medical curriculum (from the University College of Nephrology Teachers) (12), and then to the treatment recommended by the relevant European guidelines (12,13). The answers were stratified by the years of study.

2.3. Statistical analysis

The analyses were performed using SAS® R9.4 software (SAS Institute, Cary, NC, USA). The bilateral significance level was set at $p < 0.05$.

All of the students' answers, which were generally binary, were proportionally described in the general population according to the year of study. Those regarding the hyperkalemia and hypokalemia thresholds were categorized; their distribution was analyzed according to the year of study.

The proportion of answers that were in keeping with the curriculum and the relevant European recommendations/literature data/expert opinions were based on indicator variables. These were created from the students' answers, as well as the information in the curriculum and the European guidelines.

Each indicator variable was rated "1" if the student's answer was in keeping with the medical curriculum or the guidelines, and "0" if the answer was non-compliant.

The results were compared according to the years of study using Fisher's exact test, and the thresholds of dyskalemia according to the years of study were compared using a Chi^2 test of homogeneity.

3. Results

The percentage of questionnaires returned was 81.2% (n=290/357). Three questionnaires were partially completed and were not included (Figure 1).

3.1. Description of the population

The general medicine students who responded to the questionnaire were evenly distributed among the three years of internship (33.8% in the first year, 35.9% in the second year, and 30.3% in the third year).

3.2. Overall results and by the years of study and compare with the relevant guidelines

3.2.1. Limits of kalemia considered to be pathological

The students considered a mean hyperkalemia of 5.1 mmol/L to be pathological. The minimum hyperkalemia value proposed by one student was 3.5 mmol/L and the maximum value was 6.5 mmol/L. The mean hypokalemia considered to be pathological by the students was 3.4 mmol/L (minimum 2.5 mmol/L and maximum 3.8 mmol/L). (table 1)

		Hyperkalemia threshold				**Hypokalemia threshold**			
Year	n=287	**K< 5** **17 (5.9%)**	**K=5** **192 (66.9%)**	**5 < K ≤ 5.5** **71 (24.7%)**	**K > 5.5** **7 (2.4%)**	**K < 3** **8 (2.8%)**	**3 ≤ K < 3.5** **53 (18.5%)**	**K=3.5** **224 (78%)**	**K > 3.5** **2 (0.7%)**
1st	n=97	10 (18.2%)	72 (74%)	11 (11.3%)	4 (4.1%)	4 (4.1%)	16 (16.5%)	76 (78.4%)	1 (1%)
2nd	n=103	6 (5.8%)	61 (59.2%)	34 (33%)	2 (1.9%)	3 (2.9%)	17 (16.5%)	82 (79.6%)	1 (1%)
3rd	n=87	1 (1.1%)	59 (67.8%)	26 (29.9%)	1 (1.1%)	1 (1.1%)	20 (23%)	66 (79.5%)	0 (0%)
		p=0.0005				*p=0.85*			

Table 1: Hyperkalemia and hypokalemia threshold (mmol/L) according to the years of study.

There was a statistically significant difference in the hyperkalemia thresholds for the different years of study (p=0.0005). Nearly a quarter of the students rated the threshold for hypokalemia as being strictly below 3.5 mmol/L (21.3%, n=61/287) (Table 1).

The kalemia thresholds considered to be pathological according to the curriculum (11) and the relevant guidelines (13) were the same (hypokalemia = 3.5 mmol/L and hyperkalemia = 5.0 mmol/L). This hypokalemia threshold was indicated by 78% (n=224/287) of the students, while this hyperkalemia threshold was indicated by 66.9% (n=192/287) of the students, and 59.6% (n=171/287) of the students correctly identified both of these pathological thresholds.

3.2.2. Perception of danger

More than half of the general medicine students thought that severe hyperkalemia was more of a “concern” than severe hypokalemia (60.3% (n=173/287) vs. 26.5% (n=76/287)); for

10.8% (n=31/287) both types of kalemia were a concern, while for 2.4% (n=7/287) severe dyskalemia was not a concern. The students' answers were similar across all internship years (p=0.74).

There was no difference in terms of what the students had been taught regarding the danger associated with hyperkalemia versus hypokalemia. The Expert Consensus of the European Society of Cardiology has stated that hypokalemia maybe even more dangerous than hyperkalemia (14) (only 26.5% (n=76/287) of the students shared this opinion).

3.2.3. Clinical cases and comparison with evidence by medicine

The students were presented with 3 hypothetical clinical situations:

1/ Isolated hypokalemia at 2.6 mmol/L (Figure 2)

Most of the students stated that they would perform an electrocardiogram (ECG) (79.8%, n=229/287) and oral potassium supplementation (70.7%, n=203/287); while 16.7% (n=48/287) would provide intravenous supplementation. Half of them (53.7%, n=154/287) would request another kalemia test and 59.9% (n=172/287) would perform additional biological tests. Only a quarter of the students (28.6%, n=82/287) would undertake oral questioning and a clinical examination of the patient. They were generally not inclined to ask for advice from a specialist (28.6%, n=82/287). The further along the student was with their studies, the less likely they were to perform an electrocardiogram (ECG) in case of isolated hypokalemia (p=0.0001). On the other hand, they would more often request additional biological tests (p=0.004). The students in the second year were the most inclined to supplement with potassium (p=0.029) and they were the least inclined to refer their patients to the emergency department or to a hospital (p=0.025). There was not a statistical difference between the internship year in terms of checking the kalemia a second time (p=0.33) or performing an interview and a clinical examination (p=0.47).

More than 50% of the students provided answers that were in keeping with the medical curriculum and with the data in the literature, except for the items "Interrogation/clinical examination" (28.6%, n=82/287) and "Diet rich in potassium" (1.4%, n=4/287). The major difference lies in the way the patient would be supplemented with potassium: 70.7% (n=203/287) of the patients would be given an oral supplementation in accordance with the data in the literature (15,16). Indeed, interrogation, clinical examination and further investigations are essential to determine whether the patient should be hospitalized, and if so,

the route of administration will be intravenous. If there is good tolerance and no signs of severity, the route of administration will be oral. There is no discrepancy between curriculum and expert opinion.

2/ Isolated hyperkalemia at 5.7mmol/L (Figure 3)

Approximately three-quarters of the students indicated that they would first request another kalemia test (75.3%, n=216/287). An ECG was favored by 59.9% (n=172/287), and slightly less than half would prescribe an ion-exchange resin (44.9%, n=129/287) or additional biological testing (47%, n=135/287). Very few would undertake oral questioning and a clinical examination of the patient (15.7%, n=45/287) or ask for the opinion of a specialist (20.6%, n=59/287). Students in the first year of internship were the most likely to favor performing an ECG ($p < 0.0001$) and to treat the patient with Polystyrene Sulfonate (p=0.0002), while students in the second year were the least likely to recommend an ECG ($p < 0.0001$) and to treat with Polystyrene Sulfonate (p=0.0002). There was not a statistical difference between the year of study with regard to checking the kalemia a second time to rule-out false hyperkalemia (p=0.21) or performing additional biological tests (p=0.098).
In case of true hyperkalemia (excluding false hyperkalemia secondary to hemolysis and/or delayed blood centrifugation), three items were different between the medical curriculum and the expert opinions: the students agreed with the curriculum in terms of performing an ECG (59.9%, n=172/287) but also with the experts' opinions in regard to not performing additional biological examinations (53%, n=152/287) or prescribing Sodium Polystyrene Sulfonate (55.1%, n=158/287), at this level of kalemia.

3/ Hyperkalemia of 6.0 mmol/L in a patient with heart and kidney failure (Figure 4)

The answers of the students regarding the management of this situation were very heterogeneous: half of them would perform an ECG (51.2%, n=147/287, 51.6% of the students would discontinue the MRA and/or ACE inhibitor (n=148/287), while a third would reduce their dose (34.5%, n=99/287). More than a third of the students (39.7%, n=114/287) stated that they would treat this hyperkalemia with an ion-exchange resin. Less than half of the students (42.5%, n=122/287) indicated that they would ask for specialist advice. The further along the general medicine student was with their studies, the more they favored prescribing an ion-exchange resin (p=0.023), and the more they would perform another check

of the kalemia ($p < 0.0001$) to rule-out a false hyperkalemia (due to the sampling process e.g. at home, with delayed centrifugation leading to hemolysis) and additional biological examinations ($p=0.024$). There was not a statistical difference between the years of study in regard to whether they would perform an ECG ($p=0.42$) or transfer the patient to the emergency department ($p=0.085$).

Several items were discordant between the medical curriculum and the guidelines: the students' answers were in keeping with the European guidelines to not undertake additional biological examinations (80.1%, n=230/287). On the other hand, only 3.8% (n=11/287) followed the guidelines for "temporary" discontinuation of MRA and/or ACE, and more than 51.6% (n=148/287) recommended "permanent" discontinuation. Increasing the dosage of Furosemide was considered appropriate by 20.6% (n=59/287).

4. Discussion

To our knowledge, this is the first study to evaluate the competence and the perception of danger of graduating French general medicine students regarding dyskalemia.

- The knowledge regarding the management of dyskalemia was highly variable from one student to the next and according to how close they were to completion of their medical degree.
- The thresholds for dyskalemia were not well known and there was inadequate recognition of the risk associated with hypokalemia.
- French medical students appear to favor the use of ion exchange resins. This is specific to France and probably due to what is taught in the medical curriculum.
- In case of hyperkalemia in the context of heart and renal failure, management was mostly focused on the renal risk, while ignoring the cardiovascular benefit.
- The students tended to be disinclined to examine patients in case of dyskalemia.
- The students tended to see little merit in engaging a specialist when faced with dyskalemia.
- The use of ECG decreased as the studies progressed, probably because the internship in the GP's office has not yet been completed in the seventh-year initial formation.

4.1. Variability of the answers

We were surprised to discover that some students considered extreme and dangerous values to be the pathological thresholds for kalemia: 2.5 mmol/L for hypokalemia and 6.5 mmol/L for hyperkalemia.

The greatest diversity in the answers related to hyperkalemia with heart and renal failure, and was dependent on the level of advancement in the specialty, especially in regard to the prescription of Sodium Polystyrene Sulfonate (28.9% of students in the first year of internship versus 47.1% in the third year) and performing a second kalemia test to rule-out a false hyperkalemia due to the sampling process (19.6% in the first year versus 49.4% in the third year). Four students even stated that they would stop all treatments (1.4%), which is generally thought to be extremely dangerous for the patient.

In case of isolated hypokalemia, management varied also according to the years of study: students in the second year of internship were the most likely to supplement by oral administration and to not refer their patients to the emergency department, unlike the other two years. In addition, there was a difference in the way the potassium would be supplemented: 16.7% would do so intravenously versus 68.3% favoring oral administration.

In the case of isolated hyperkalemia, the approach of the seventh-year medical students was essentially to perform an ECG, to treat with Sodium Polystyrene Sulfonate, and to recheck the kalemia, whereas the approach of the ninth-year medical students was to initially only recheck the kalemia. The thresholds considered pathological are different in each laboratory, and students rely on these standards to manage hyperkalemia.

4.2 Inadequate recognition of the risk related to hypokalemia

The risk associated with hypokalemia is often underestimated by students. Indeed, mortality is significantly increased below a threshold of 4.1 mmol/L in case of hypertension (1) or chronic heart failure (17), and 3.9 mmol/L in case of acute heart failure after myocardial infarction (18). Several studies have also shown that hypokalemia is associated with increased mortality in heart failure (19), and that blood potassium levels below 4.0 mmol/L are associated with an increased risk of all-cause mortality, mortality from cardiovascular disease and progressive heart failure, and an increased rate of all-cause and cardiovascular hospitalizations (9,20). Hypokalemia increases the risk of ventricular arrhythmia and cardiac arrest (2,21); a decrease in blood potassium by 1 mmol/L increases the risk of ventricular arrhythmia by 28% (22). In case of cardiac arrest, kalemia is thought to be significantly lower than in controls, and survivors are often hypokalemic (23-25).

There is a U-shaped relationship between kalemia and all-cause mortality, and levels of potassium that are considered "normal" are also associated with an increased risk of death. In general, the more the potassium level deviates from normal, the higher the mortality (1).

4.3. Widespread use of ion-exchange resins

French general medicine students are taught to use Sodium Polystyrene Sulfonate (SPS), which is an ion-exchange resin. This is in accordance with the practices of French doctors, who use SPS much more frequently than their German, Italian, Spanish, and English colleagues (26). However, there is no evidence regarding the efficacy of SPS in the emergency treatment of hyperkalemia (27, 28). The optimal rate of correction for hyperkalemia is unknown, and the relevance of an immediate decrease of kalemia in patients without cardiac manifestations of hyperkalemia has not been demonstrated (29). Additionally, this drug has not been rigorously evaluated in clinical trials to prove its efficacy and safety in acute or chronic hyperkalemia (30). Since the counter-exchange ion is sodium, extreme caution should be taken in patients with heart failure, as such patients cannot tolerate even a small increase in sodium load (30). It should be noted that SPS has marketing authorization (MA) in France for medical services rendered that are considered important. This drug was indicated as a first-line treatment for hyperkalemic patients in the French medical curriculum (12) at the time that the questionnaire was distributed (June 2017). This has been modified in the new version of the curriculum released in 2018 by the University College of Nephrology Teachers (version 8), which no longer considers SPS as a necessity but as an option in case of hyperkalemia. Of importance, none of the new-generation potassium binders is reimbursed in France to date, therefore preventing from any related teaching process.

4.4. Management of hyperkalemia in heart and renal failure

The management of hyperkalemia by French general medicine students differs quite considerably from the European guidelines. They tend to discontinue ACE inhibitors and/or MRAs without considering reintroducing them, which can adversely affect patients as the morbi-mortality increases without the use of an optimal dose of these drugs (30-32). Trevisan et al. have shown that after hyperkalemia, 47% of MRA treatments are halted, and they are not reintroduced in 76% of cases (33). Discontinuation of RAAS inhibitor therapy is associated with an increased risk of cardiovascular morbidity and mortality and total mortality (14). The European guidelines in regard to heart failure tolerate a maximum hyperkalemia threshold of 6.0 mmol/L. Above this limit, RAAS inhibitors should be discontinued for a

time, but not definitively; between 5.5 and 6.0 mmol/L, there can be brief discontinuation or dose reduction (13,14). Thus, the European guidelines emphasize the need to try to reintroduce RAAS inhibitors as soon as possible, when they have been temporarily halted or the dosage decreased due to hyperkalemia, with close monitoring of kalemia and renal function (13). Increasing the dosage of furosemide, considered as appropriate by 20% of the students, is an acceptable solution in case of hyperkalemia, but it should however be avoided in case of AKI and signs of dehydration.

The management is in accordance with what is taught in the Nephrology module of the medical school curriculum in the chapter entitled "Potassium balance abnormalities" (12). This is theory-based teaching that does not consider the complexity encountered in case of comorbidities such as the association with heart failure, and which recommends, in the case of moderate hyperkalemia, "eviction of hyperkalemic drugs", without their subsequent reintroduction. The risk/benefit ratio of hyperkalemia is not emphasized in teaching, and general medicine students tend to refer to "*Primum Non Nocere*", which is a concept that has become obsolete.

On the other hand, in the chapter regarding how to treat chronic renal failure, the possibility of "temporary" discontinuation of ACE inhibitors or ARA2 is discussed, without any reference to anti-aldosterone drugs, which are not mentioned in the curriculum. However, this information is too "diluted" to be taken in by the students, especially as it contradicts the information in the chapter "Potassium balance abnormalities".

Medical students are faced with contradictions that are even more prejudicial, as there is no clear consensus regarding the management of these patients with cardio-renal syndrome in general practice. The fear of inducing serious secondary effects (hyperkalemia, deterioration of renal function) has led some doctors to avoid RAAS inhibitors (6), without considering the demonstrated benefit of these molecules on morbi-mortality in the event of heart failure (5, 34,35). Moreover, the use of RAAS inhibitors in France is low compared to Germany, Italy, Spain, and the United Kingdom (26). For this reason, the use of new experimental potassium chelating agents (patiromer or sodium zirconium cyclosilicate (ZS-9)) could be an option in the near future to compensate for this under-prescription (36-40). These drugs have a European MA but are not presently available in France.

4.5. Limited use of interrogation and clinical examination

Surprisingly, we found that the students were very rarely inclined to carry out an interrogation and clinical examination of patients with dyskalemia, even though this is generally considered

to be essential during a medical consultation. In case of dyskalemia, it is crucial to identify any dietary issues and clinical elements associated with dyskalemia and to provide advice accordingly. Very few students introduce, and therefore explain to the patient, a potassium-rich diet in case of hypokalemia, whereas it is recommended in association with supplementation (41,42).

4.6. Limited use of specialists

The students indicated that they would rarely request specialist advice and rarely refer their patients to hospitals or emergency departments in case of isolated dyskalemia. They are inclined to manage these situations on their own, especially if they are advanced in their studies. The use of specialists and hospitalization is also low among practicing GPs, ranging from 5.8 to 6.6% according to the study (43-45).

4.7. Use of the ECG

For isolated dyskalemia discovered in general practice, students in the first year of internship more often recommend performing an ECG than those in the following two years of study. This may be a result of the internship with a general practitioner. Indeed, although the availability of the required equipment in doctors' offices varies from 49% to 86% according to the study, the frequency of their use is at least once a week for half of the doctors who have an ECG device available (46,47). Moreover, an ECG is not a very sensitive indicator of the severity of dyskalemia. Cardiac manifestations may be non-specific or absent at potassium concentrations that are associated with a risk of mortality (29). In case of hyperkalemia, an ECG is recommended above 6.0 mmol/L (29), whereas in case of hypokalemia, it is recommended for all patients, irrespective of their potassium level (49).

4.8. Strengths and limitations of the study

The main strength of this study lies with the use of an open-ended questionnaire, which ensured that there were no leading questions.

We limited the potential for bias by clearly explaining the objectives of the study and how the questionnaire was to be filled out before completing it. The questionnaires were filled out in the presence of a friendly and neutral team, without direct intervention but with immediate availability of assistance if required (self-administered questionnaire).

Methodological bias was minimized by providing resources to organize the task of collecting, analyzing, and processing the information. The questions asked were intended to be straightforward, short, neutral, and without ambiguity.

Naturally, sample selection bias cannot be fully ruled out, although we are confident that we were able to ensure adequate representativity of the population of students enrolled in French general medicine studies.

The bias linked to the "experience" of the general medicine students could be assessed by the last question, although this question contained ambiguities. In June 2017, the students who had just started a new stage of internship on May 1st did not necessarily include this in their answer. Indeed, "current or ongoing internships" was not specified. There was, therefore, a loss of information.

The questionnaire is not without its limitations, but overall, we avoided many of the potential biases by excluding any leading questions and by reducing the time needed to complete the questionnaire. The questions were open-ended so as not to suggest possible answers to the situations described.

In conclusion, the validity of the results clearly needs to take into account the limitations mentioned above, but these do not significantly detract from the coherence and overall meaning of the results.

5. Conclusion

The medical curriculum cannot always take into account the complex situations experienced in clinical practice. Our study points out a lack of coherence between what is taught regarding the management of dyskalemia and the guidelines regarding patients with heart and renal failure. This often results in inadequate management and a reluctance to reintroduce drugs prone to induce hyperkalemia (ACE/ARA2 and MRA) after an initial episode of hyperkalemia. This at least in part explains why France has the lowest level of RAAS inhibitor use in Europe (27), and why these drugs are often used at a suboptimal dosage in heart failure. This is quite the opposite in case of chronic kidney insufficiency, for which France has the highest level of RAAS inhibitor use in Europe (50).

It is essential for medical students to very early on be faced with complex situations in the management of cardio-renal syndrome, due to the increasing prevalence of this syndrome among older patients with diabetes, heart failure, and kidney disease.

Medico-administrative data such as the SNDS (Système National de Données de Santé) are collected by the Primary Health Insurance in France, but the tools proposed to SNDS users make their in-depth exploitation difficult. A view based on a generic model of care trajectories could make it possible to identify situations in which the trajectory of care can be improved (e.g., severe hypokalemia, severe hyperkalemia) and thus serve as a basis for more pragmatic teaching, adapted to general practitioners. (51)

Indeed, the recent opening of access to the French nationwide health record database SNDS is a great opportunity to carry out comprehensive health studies at the country level. Happe and Drezen have proposed a toolbox to query and cope with the complexity of care pathways of patients, because access is very difficult for nonexpert data scientists. This toolbox is particularly suitable for understanding timeline representations of individual patient healthcare trajectories in case of heart failure and cardiorenal syndrome. (52)

It would also be appropriate to standardize the guidelines and the curriculum in order to provide pragmatic instruments to help with the management of dyskalemia in patients with heart failure and kidney disease, either as a decision tree or a dedicated computer tool.

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a. Contributorship statement:

Lisa Senninger: Research design, data collection, data entry, writing.
Laure Abensur-Vuillaume: Proofreading, partial writing
Luc Frimat: Proofreading, partial writing
Nicolas Girerd: Proofreading, partial writing
Zohra Lamiral: statistical review
Patrick Rossignol: Proofreading, partial writing
Jean-Marc Boivin: Research design, Proofreading, partial writing

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c. Funding: none

d. Data sharing statement: All data are available on request to the corresponding author.

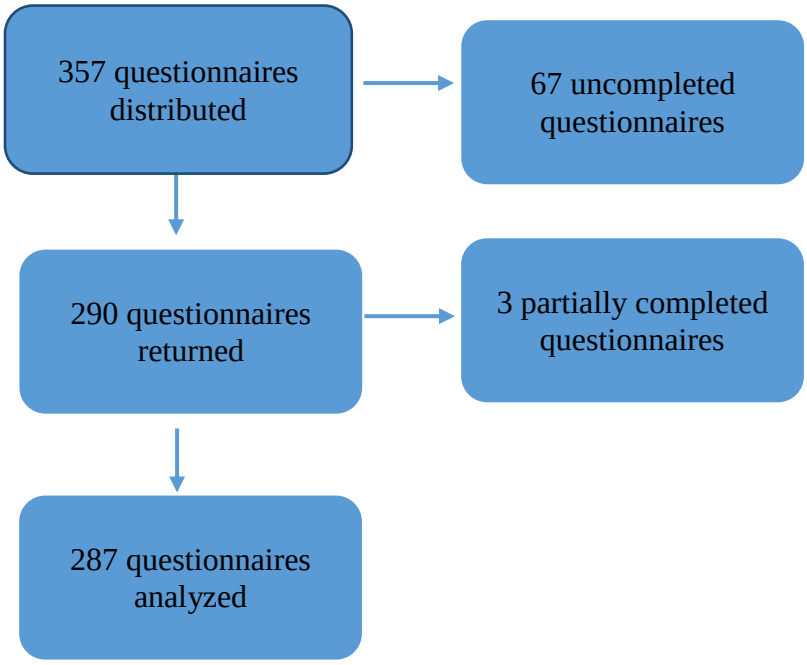

Figure 1: Flowchart of the participants

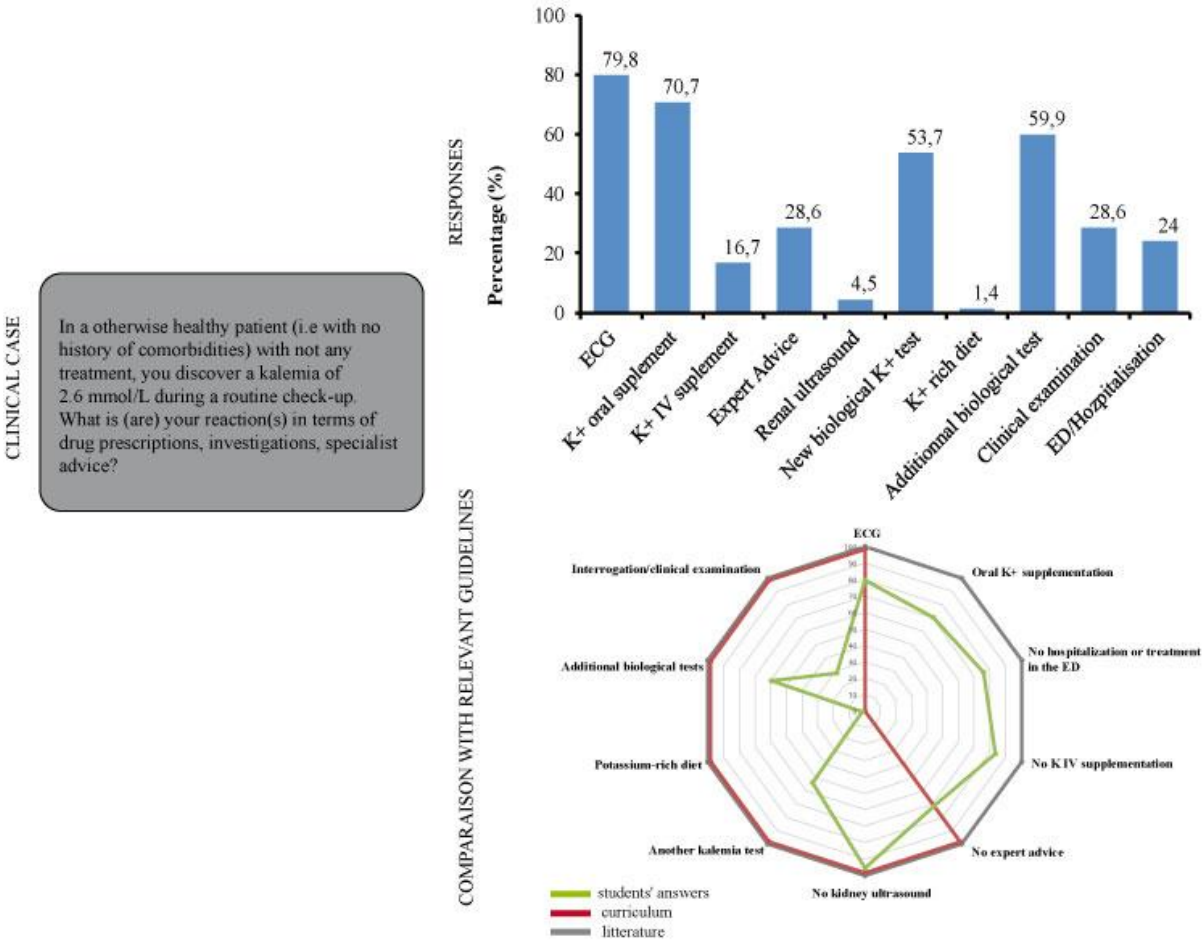

Figure 2: Hypokalemia of 2.6mmol/L in a patient who is not on any treatment: student's responses and comparison with literature and curriculum

The radar chart is represented by student's answers in green, curriculum in red, and expert opinion in grey.

Legend: IV (intravenous), ED (emergency department).

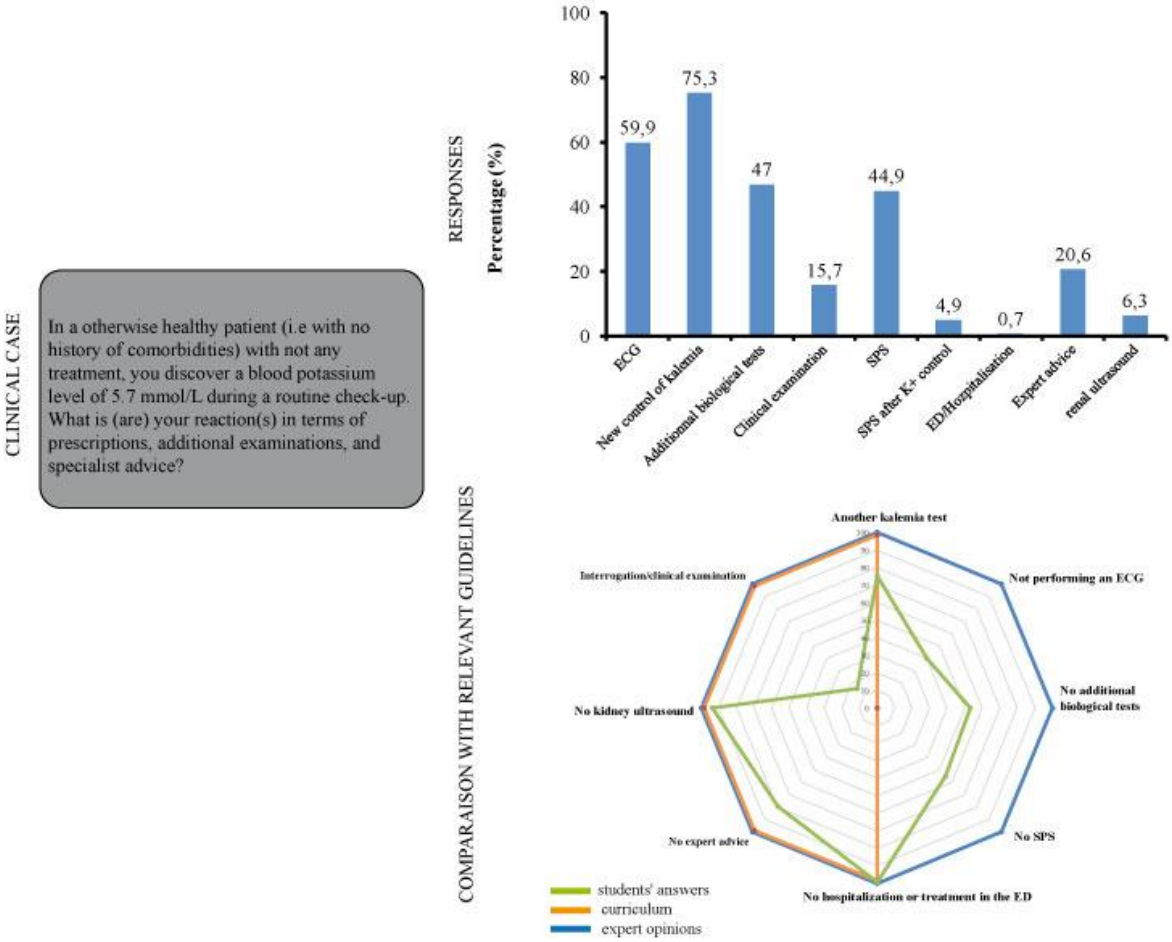

Figure 3: Hyperkalemia of 5.7mmol/L in a patient who is not on any treatment: student's responses and comparison with expert opinions and curriculum

The radar chart is represented by student's answers in green, curriculum in orange, and expert opinion in blue.

Legend: ARM (Angiotensin Receptor Agonist), ACE (Angiotensin-comverting enzyme inhibitors), SPS (Sodium Polystyrene sulfate), ED (emergency department).

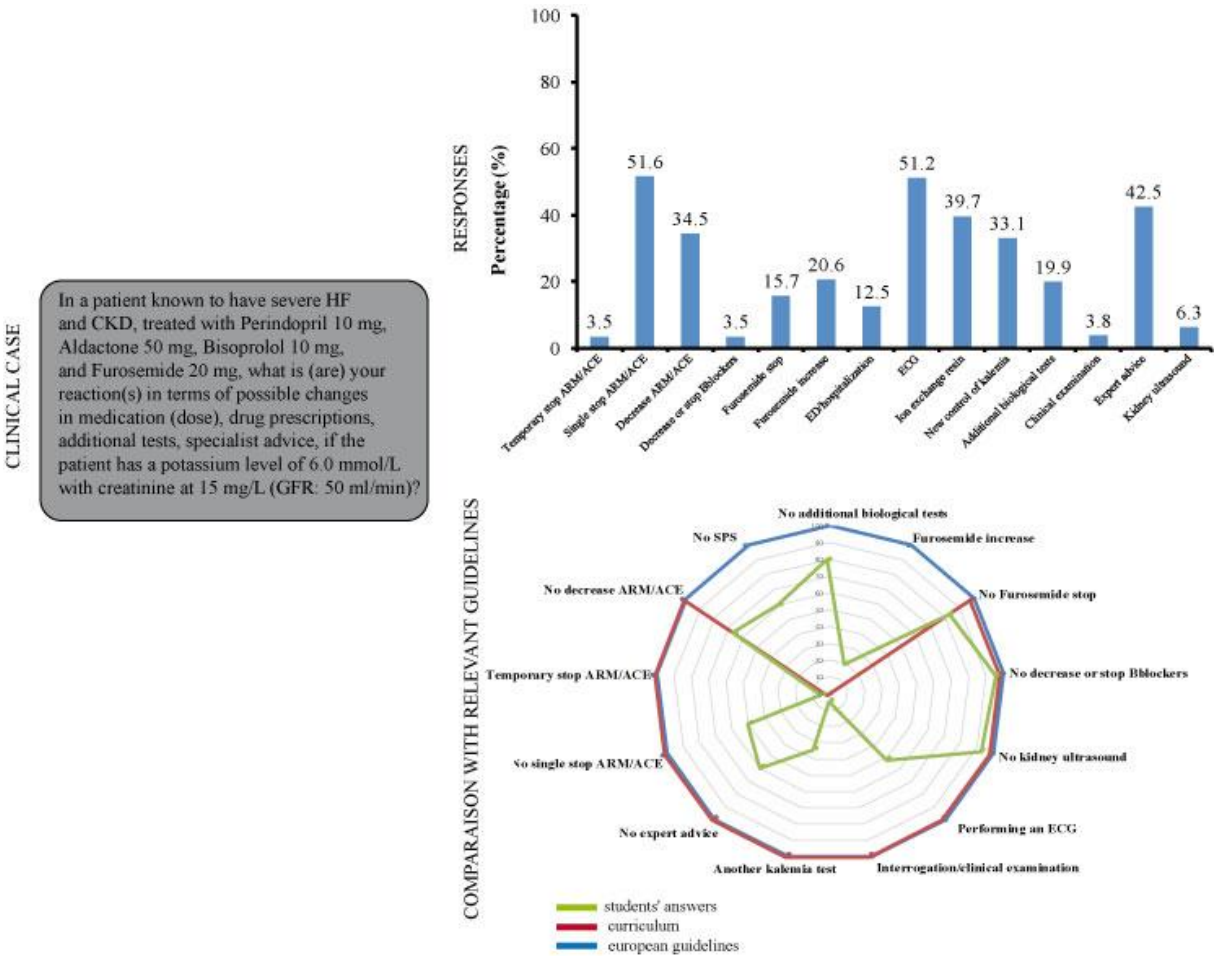

Figure 4: Hyperkalemia of 6.0mmol/L in a patient with heart and kidney failure, student's responses and comparison with European guidelines and curriculum

The radar chart is represented by student's answers in green, curriculum in red, and expert opinion in blue.

Legend: ARM (Angiotensin Receptor Agonist), ACE (Angiotensin-converting enzyme inhibitors), SPS (Sodium Polystyrene sulfate), ED (emergency department), GFR (Glomerular filtration rate), HF (Heart failure), CKD (Chronic kidney disease).

		Hyperkalemia threshold				Hypokalemia threshold			
Year	n=287	**K< 5** **17 (5.9%)**	**K=5** **192 (66.9%)**	**5 < K ≤ 5.5** **71 (24.7%)**	**K > 5.5** **7 (2.4%)**	**K < 3** **8 (2.8%)**	**3 ≤ K < 3.5** **53 (18.5%)**	**K=3.5** **224 (78%)**	**K > 3.5** **2 (0.7%)**
1st	n=97	10 (18.2%)	72 (74%)	11 (11.3%)	4 (4.1%)	4 (4.1%)	16 (16.5%)	76 (78.4%)	1 (1%)
2nd	n=103	6 (5.8%)	61 (59.2%)	34 (33%)	2 (1.9%)	3 (2.9%)	17 (16.5%)	82 (79.6%)	1 (1%)
3rd	n=87	1 (1.1%)	59 (67.8%)	26 (29.9%)	1 (1.1%)	1 (1.1%)	20 (23%)	66 (79.5%)	0 (0%)
		p=0.0005				*p=0.85*			

Table 1: Hyperkalemia and hypokalemia threshold (mmol/L) according to the years of study.