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Does Applying Biomedical Knowledge Improve Diagnostic Performance When Solving Electrolyte Problems?

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Abstract

Background: If experienced physicians apply clinical rather than biomedical knowledge when diagnosing, why do we use the basic sciences as the foundation for clinical teaching? In this study our objective was to evaluate the contribution of biomedical knowledge to diagnostic performance.

Method: We asked 13 medical students and 19 nephrologists to solve electrolyte problems while thinking aloud, and determined the application of biomedical concepts from protocol analysis. We used logistic regression to study the association between biomedical concepts, clinical experience, and diagnostic performance.

Results: Students and nephrologists applied a similar number of relevant biomedical concepts per case (M = 1.8 SD = 1.1 vs. M = 1.8, SD = 1.2), respectively, p = 0.80), but nephrologists had better diagnostic performance (86.8% vs. 63.5%, respectively, $p < 0.01$). Experience modified the effect of applying biomedical concepts on diagnostic performance. For students the odds of success increased significantly with applying biomedical concepts (odds ratio 4.66 [2.07, 10.48], $p < 0.001$), whereas for nephrologists there was only a trend towards improved performance (odds ratio 1.72 [0.94, 3.11], p = 0.07).

Conclusions: Our results suggest that improving biomedical knowledge should improve students' diagnostic performance on electrolyte problems, but it is unclear if this approach will also be effective in experienced physicians.

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Introduction

As physicians accrue clinical experience they increasingly apply clinical rather than biomedical knowledge when diagnosing.[1] Yet medical educators typically use the basic sciences as the foundation for clinical teaching, encouraging learners to integrate biomedical and clinical knowledge, and to provide a biomedical justification for their diagnoses. So how can we justify this paradox? Is biomedical knowledge like training wheels, to be cast off as soon as we can ride safely, or does it actually advance diagnostic performance?

Prior studies evaluating the contribution of biomedical knowledge to diagnostic performance have yielded conflicting results. Patel and colleagues asked medical students to read and recall relevant biomedical texts after which they read and recalled text describing the patient's clinical problem (bacterial endocarditis), and provided a diagnosis along with an explanation of the underlying pathophysiology.[2] Finding that students applied biomedical knowledge inconsistently or incorrectly when explaining their diagnosis, the authors concluded that clinical and biomedical knowledge are distinct entities – clinical knowledge being used to diagnose and biomedical knowledge being used to provide a pathophysiological explanation – so that biomedical information is redundant when diagnosing.

But others would contest this conclusion. Studying residents and experienced radiologists diagnosing chest X-rays, Lesgold *et al*.[3] found that correct interpretation involved the explicit use of anatomical and pathophysiological knowledge, and that experienced radiologists applied more of this knowledge than residents. Similarly, when Gilhooly *et al*.[4] studied medical students, house officers, and registrars diagnosing abnormal electrocardiograms they found increasing application of biomedical knowledge (and improved performance) with clinical experience. The conclusion from these studies was that applying biomedical knowledge augments diagnostic performance.

Are the results from the latter studies simply a case of applying more information is better than less? Probably not. Limited by the capacity of working memory, as we apply more information to a case we increase the cognitive load so that performance may actually decline.[5,6] A nice demonstration of this was shown by Kulatunga-Moruzi *et al*.[7] who studied experienced physicians and residents diagnosing photographs with and without a comprehensive list of clinical features, both for and against the correct diagnosis. They found that performance of experienced physicians was impaired by a comprehensive feature list, but that using fewer pieces of data, all supporting the correct diagnosis, improved performance. These findings suggest that the effect of applying knowledge when diagnosing depends upon both the amount of knowledge and its relevance to the case. Thus, under some circumstances it is possible that applying biomedical knowledge to a clinical case may not be helpful, and could even be detrimental.

In the present study we observed students and experienced physicians diagnosing electrolytes and acid-base problems, an area in which, based upon prior research, we felt the application of biomedical knowledge might be relevant.[8] Our objective was to describe the contribution of biomedical knowledge to diagnostic performance in this area. We considered three possible effects of biomedical knowledge: *redundant*, in which case there should be no association with performance, *conducive*, where performance should be positively associated with applying more biomedical knowledge, and *detrimental*, where performance should be negatively associated with applying more biomedical knowledge. Recognizing that clinical experience may influence how biomedical is applied during problem solving – specifically experienced physicians may encapsulate biomedical knowledge within clinical knowledge[9] – we also explored whether clinical experience modified the effect of biomedical knowledge on diagnostic performance.

Methods

This was a cross-sectional, observational study of 13 first year medical students and 19 nephrologists at the University of Calgary. We recruited students after they completed the section on electrolyte and acid-base problems in the undergraduate Renal Course.

Format of the electrolyte and acid-base cases

We used four real-life electrolyte and/or acid-base cases. The correct diagnoses for Cases 1-4 were: hyponatremia due to primary polydipsia; hyperkalemia due to normal anion gap metabolic acidosis; combined anion gap and normal anion gap metabolic acidosis due to bicarbonate loss from diarrhea and lactic acidosis, respectively, along with respiratory acidosis; and combined metabolic alkalosis and respiratory acidosis due to surreptitious vomiting.

Each case began with contextual clinical information including presenting symptoms and signs, clinical setting, demographic information, past history and medications. This was followed by laboratory information including serum electrolytes, urine electrolytes and arterial blood gas results. For each question there was a single correct answer.

Assessment of information processing

To study information processing we analyzed think aloud protocols after audio taping and transcribing the protocols. We gave participants a complete paper version of each case in turn and asked them to solve the clinical problem while thinking aloud – verbalizing all thoughts as they arose – and to select the most likely diagnosis. We did not ask for an explanation or justification for diagnoses as we felt that this may bias information processing towards the application of biomedical knowledge.[10] As such, we hoped to capture 'incidental' rather than 'intentional' application of biomedical knowledge.

In our study we did not restrict time for task completion, rather we adopted a 'naturalistic' approach whereby our participants could take as much time as needed to provide their diagnoses. We chose this approach as we felt it unrealistic for students and nephrologists to complete the tasks in the same time period, and also because participants may apply less knowledge if they are forced to rush information processing.

As previous studies have found that expert performance in medicine is not explained by experts simply processing of more information[11], we focused our analysis on the application of key biomedical concepts, which we identified *a priori* for each case. At the University of Calgary the key concepts for each clinical presentation are agreed upon by faculty with domain expertise and are incorporated into diagnostic schemes that are given to students.[12] When analyzing the think aloud protocols we identified whether or not our participants verbalized these specific biomedical concepts. For example, for the case of hyperkalemia key biomedical concepts include glomerular filtration rate, transtubular potassium gradient (TTKG), and anion gap. An example of a transcript, from a nephrologist, where these concepts were correctly applied is given below:

*"I want to look at the urine handling of potassium. The **TTKG** is 10.1 – so the principle cell **is doing what it should be doing in the face of hyperkalemia**, although I note that the urine chloride is low – so there maybe some reduction in the distal delivery of sodium to the cortical collecting duct. The creatinine is 112 – so there is **enough glomerular filtration** for it to be able to filter potassium and lead to its excretion. The likely explanation for hyperkalemia in this setting is due to a shift. So what might cause the shift? Bicarb is 12; she has a **normal anion gap acidosis**. This would lead to the buffering of hydrogen ions and displacement of the potassium from the ICF to the ECF causing hyperkalemia which, given the lack of evidence to support cell lysis or any other cause, would suggest that this is the diagnosis here."*

Statistical analyses

To study the association between the application of biomedical knowledge and diagnostic performance we used backward elimination multiple logistic regression to allow us to adjust for the effect of clinical experience. We considered interaction in our model and compared nested models using the likelihood ratio test. We performed all statistical analyses using Stata 8.0 software (Stata Corporation, College Station, Texas).

Ethical considerations

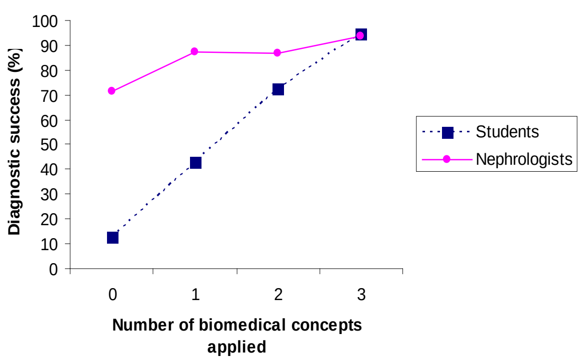
We received ethical approval from the Conjoint Health Research Ethics Board at the University of Calgary and obtained informed consent from all subjects. We removed the original form of identification (name or student ID) and replaced this with a computer randomized study number to ensure anonymity of subjects and blinding of raters.

Results

During problem solving students and nephrologists applied a similar number of relevant biomedical concepts per case (M = 1.8, SD = 1.1, vs. M = 1.8, SD =

1.2, respectively, $p = 0.80$), but nephrologists had a higher diagnostic success rate than students (86.8% vs. 63.5%, respectively, $p < 0.01$). In our logistic regression model we found a significant interaction between expertise and the association between applying biomedical concepts and diagnostic success ($p < 0.05$). Using a stratified analysis we found that for students the odds of success increased significantly with applying biomedical concepts (odds ratio 4.66 [2.07, 10.48], $p < 0.001$). For nephrologists there was a trend towards improved performance when applying additional biomedical concepts, although this did not reach statistical significance (odds ratio 1.72 [0.94, 3.11], $p = 0.07$). The relationship between performance and application of biomedical concepts for students and nephrologists is shown in Figure 1.

Figure 1. The relationship between application of relevant biomedical concepts and diagnostic performance for students and nephrologists.



Discussion

In this study we found that students and experienced physicians used the same number of key biomedical concepts when diagnosing, but with different results; as expected, experienced physicians outperformed students. Clinical experience modified the effect of biomedical knowledge on performance: in students there was a strong, positive, and statistically significant association, compared to a non-significant positive trend in experienced physicians. This suggests that applying biomedical knowledge augments performance in students, but may be redundant in experienced physicians, or weakly conducive, so that our study was underpowered to find a significant association. So why does clinical experience modify this effect?

When diagnosing both clinical and biomedical knowledge may be applied to a new problem. Our participants varied widely in their clinical experience, from minimal in first-year students to more than five years in all of our experienced physicians. The strong effect of applying biomedical knowledge in students likely reflects the dearth of their clinical knowledge. By comparison, experienced physicians could supplement their biomedical knowledge with clinical knowledge, thus explaining why they were less dependent upon biomedical knowledge, and why they could perform better than students despite applying the same amount of biomedical knowledge. An alternative explanation is that experienced physicians actually applied more biomedical knowledge than students, but did so indirectly – through its encapsulation within clinical knowledge.[9,13,14]

Teaching implications

So how can we use these results to improve learning outcomes? Finding that diagnostic performance of medical student on electrolyte and acid-base problems is enhanced when they apply biomedical knowledge suggests that improving this knowledge should be an effective teaching strategy. Consistent with this are the findings of several recent studies by Woods et al.,[15-18] in which they showed that providing a biomedical explanation of clinical features attenuates the decay of knowledge and diagnostic performance. An alternative approach is to reduce reliance on biomedical knowledge by increasing clinical knowledge, so that students have the cognitive flexibility of experienced physicians. These strategies are, of course, not mutually exclusive and the combination may be better than either alone.

The teaching implications for experienced physicians are less clear. Our results suggest that we shouldn't simply extrapolate the benefits for students to experienced physicians – because what works for one group of learners typically does not work for another.[19] Yet there may still be an argument for improving the biomedical knowledge of experienced physicians. Prior studies have shown that the amount of biomedical knowledge that experienced physicians apply when diagnosing is inversely related to the amount of clinical information provided.[20] In daily practice clinical information may be limited, unhelpful, or even misleading, and under these circumstances even experienced physicians may rely upon biomedical knowledge when diagnosing. We only found a trend towards improved diagnostic performance when experienced physicians applied biomedical knowledge, but this may reflect the fact that our cases had helpful clinical information. Under these conditions biomedical information may indeed be redundant, but in cases without helpful clinical information even experienced physicians may rely upon biomedical knowledge to yield a correct diagnosis.

Study limitations

There are some limitations to this study. The observational cohort design allows us to study associations rather than test hypotheses or study causality. Thus we can only say that we found an association between applying biomedical knowledge and diagnostic performance; we cannot conclude that applying biomedical knowledge *caused* improved diagnostic performance. There are also limitations related to the use of think aloud protocols. Although this approach has face validity and good inter-rater reliability,[21] it only captures analytical information processing. Consequently, the contribution of automatic information processing to diagnostic performance – which is typically greater in experienced physicians – is ignored.[22,23] Our study only included first year medical students and experienced nephrologists – so we cannot comment on the association between applying biomedical information and diagnostic performance in clerks, residents or other groups of experienced physicians. Finally, the findings in the domain studied, electrolytes and acid-base problems, may not generalize to other clinical domains.

Conclusion

In this study we found that when first year medical students solved electrolyte problems applying biomedical knowledge was associated with improved performance. In experienced physicians this effect was attenuated, likely because clinical experience makes this group less reliant on biomedical knowledge when diagnosing. Our results suggest that improving biomedical knowledge of students should improve their performance. Under certain circumstances the performance of experienced physicians may also be improved by applying biomedical knowledge, but this area still requires further study before teaching recommendations can be made.

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Appendix

Hyperkalemia case

For patient with an abnormal serum potassium concentration select the SINGLE most likely diagnosis from the choices A– G.

A. lack of insulin activity
B. reduced aldosterone activity
C. primary hyperaldosteronism
D. intracellular H+ buffering (non-anion gap acidosis)
E. cell lysis (redistribution of potassium)
F. reduced activity of Na+/K+ ATPase
G. increased K+ intake

A 62-year-old female was admitted 12 days previously for management of a diabetic foot ulcer. Her serum creatinine at that time was 84 μmol/L and serum potassium 4.6 mmol/L. She was started on clindamycin (an antibiotic) to treat the infection in her foot. Five days ago she developed diarrhea and has had at least seven episodes per day for the past three days. Her medications have been unchanged since admission (Enalapril 5 mg bid and glyburide 5 mg daily) with the exception intravenous Normal saline. She has had type II diabetes for seven years and hypertension for five years. On examination her pulse is 84 beats per minute supine rising to 96 beats per minute erect. Supine blood pressure is 108/66 mmHg. The results of investigations are shown below:

Lab values:

Serum Na (mmol/L)	130 mmol/L
Serum K (mmol/L)	5.8 mmol/L
Serum HCO3 (mmol/L)	12 mmol/L
Serum Cl (mmol/L)	106 mmol/L
Blood Urea (mmol/L)	9.2 mmol/L
Serum Creatinine (μmol/L)	112 μmol/L
Plasma Glucose (mmol/L)	9.2 mmol/L
Serum Osm (mmol/L)	282 mosm/Kg
Urine Osm (mmol/L)	330 mosm/Kg
Urine K+ (mmol/L)	68 mmol/L
Urine Cl- (mmol/L)	82 mmol/L
Urine Na	23 mmol/L
Arterial P_{CO2}	28 mmHg
Arterial pH	7.24