The clinical significance of hyperkalaemia-associated repolarization abnormalities in end-stage renal disease

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Abstract

Background. Hyperkalaemia is a common potentially fatal complication of chronic kidney disease (CKD). It may manifest as electrocardiogram (ECG) changes, the earliest of which is T-wave ‘tenting’. However, this occurs in less than half of episodes of hyperkalaemia. The aim of this study was to determine what other clinical features relate to the probability of T-wave tenting; and if there is a longer-term survival difference between patients who develop tenting and those who do not.

Method. One hundred and forty-five patients with end-stage renal disease who had standard 12-lead ECG and concurrent serum potassium measurement were enrolled. The presence of tenting and the ratio of the amplitude of the tallest precordial T-wave and R-wave were determined (T:R).

Results. Tenting was as common in normal range serum potassium as hyperkalaemia (33 versus 31%) and was less common than in left ventricular hypertrophy (44%). T:R was less sensitive (24 versus 33%) but more specific (85 versus 67%) than tenting at correctly identifying hyperkalaemia ≥6.0 mmol/L. Tenting became less common with increasing age. Dialysis patients were more likely to show increased T:R that pre-dialysis Stage 5 CKD. Elevated T:R was not associated with worse cardiovascular outcome but was associated with increased risk of sudden death over a mean follow-up of 3.8 years (hazard ratio = 8.3, P = 0.021).

Conclusions. The reason for the variability in T-wave changes is not clear. The ratio of precordial T-wave to R-wave amplitude is a more specific measure than tenting but both are poorly sensitive at detecting hyperkalaemia. The greater risk for sudden death may represent a susceptibility to cardiac arrhythmia during repolarization.

Keywords: ECG; ESRD; dialysis; hyperkalaemia; repolarization

Introduction

Hyperkalaemia is a common complication of end-stage renal disease (ESRD). It is potentially fatal at values ≥6.0 mmol/L though the risk increases as serum values rise, particularly >7.5 mmol/L [1, 2]. Total body potassium is ~50 mmol/kg, and 98% of this is intracellular [3–5]. The kidneys are responsible for the excretion of 95% of waste potassium and filter 700–800 mmol/day. Hence, it is evident why loss of glomerular filtration rate means that hyperkalaemia is one of the most common reasons for patients requiring emergency dialysis [6]. It is also responsible for at least 1.2% of deaths in dialysis patients in the USA [7], though the actual figure may be greater, given the high rate of sudden or unexpected death suffered by this population. The earliest electrocardiogram (ECG) abnormality of hyperkalaemia is classically the ‘tented’ or ‘peaked’ T-wave seen in the precordial leads [8, 9]. This occurs because potassium channels are partly responsible for the repolarization phase of the cardiac action potential. High extracellular potassium leads to less negative resting membrane potential in the myocardium and subsequent rapid ventricular repolarization [1]. T-wave amplitude in a normal ECG is ≤1 mV (10 mm) [10, 11], and the tallest T-wave is usually in the precordial leads. Prominent T-waves are not specific to hyperkalaemia [12]. There is usually a direct relationship between the amplitude of the precordial T-waves and their preceding QRS complex. For this reason, it is possible that left ventricular hypertrophy (LVH) may produce tall T-waves [13]. Furthermore, hyperkalaemia does not always lead to abnormal T-waves [14–16]. The threshold of serum potassium above which changes in the ECG are manifest appears to differ from patient to patient. Though the tented T-wave is not independently associated with an immediate life-threatening state, it may be the only harbinger of rapid progression to life-threatening hyperkalaemia and in such cases, therapy is warranted. As hyperkalaemia progresses more clinically, significant changes occur. These include broadening of the QRS complex and the ‘sine’ wave ECG [8, 17], which are shown to precede cardiac arrest in animal models [18, 19].

In the absence of a baseline ECG, determining whether T-wave changes are acute and caused by elevated serum potassium is difficult. The diagnosis of tented T-waves is highly subjective, relying on clinicians’ judgement of the shape and prominence of T-waves [9, 20]. This will usually occur in the absence of a baseline ECG and with the clinician often already knowing the serum potassium. A preferred measurement would be one which is not affected by...
these potential biases. Previous studies have used the relationship between the amplitudes of the precordial R-waves and T-waves to overcome this [9, 14, 20]. However, none have compared this with tenting to establish which is a more useful clinical measurement of hyperkalaemia.

Studies of abnormalities of other measures of repolarization, such as QT interval and variability, and T-wave alternans have been shown to predict arrhythmic outcome in the general population [21–23] and occur frequently in ESRD [24–26]. We also know that sudden arrhythmic death appears to be a leading cause of the high mortality seen among dialysis patients [7], as susceptibility to arrhythmia is high during repolarization [27, 28]. It is not clear if patients who develop T-wave changes in hyperkalaemia have a similar worse outcome.

The aims of this study were therefore 3-fold. Firstly, to determine which clinical and pathological characteristics other than serum potassium are associated with tented T-waves in patients with ESRD. This may help determine the reliability of this finding in different clinical settings. A second aim was to establish whether a measurement of the relationship between precordial R-waves and T-waves is a better clinical tool than the presence of tenting, as it is less subjective and accommodates the effect of R-wave height on perceived abnormalities of the T-waves.

A final aim was to determine whether the variability of hyperkalaemia-associated T-wave changes between patients has any bearing on long-term survival in ESRD. The associated hypothesis is that patients who have a lower threshold for developing T-wave changes in hyperkalaemia are more at risk of cardiac arrhythmia.

Materials and methods

Patient selection

Patients were selected from the CRISIS (Chronic Renal Insufficiency Standards Implementation Study) prospective epidemiological study of outcomes in chronic kidney disease (CKD) [29].

Patients from this cohort were selected who were over 18 years of age and who had progressed to Stage 5 CKD (estimated GFR <15 mL/min/1.73m²). All patients were eligible regardless of renal replacement therapy modality (haemodialysis, peritoneal dialysis or transplantation) or if they were still pre-dialysis. Patients were excluded if they had ECG evidence of complete left or right bundle branch block or a paced ventricular rhythm.

A review of patient case notes was performed. ECGs were selected which fulfilled the criteria of (i) had a concurrent serum potassium reading taken within 2 h of the ECG and without intervening medical therapy between the two tests, (ii) had been taken in an elective setting such as pre-operatively, as part of transplant screening, or specifically to investigate hyperkalaemia, (iii) were not taken to investigate acute cardiac symptoms such as a suspected myocardial infarction or new arrhythmia and (iv) did not have significant baseline wander or movement artefact in the isoelectric line.

A clinical history was documented to include age, gender, ethnicity, smoking status, co-morbidities, renal replacement modality and time on dialysis. The definitions of co-morbidities used in the analysis were coronary artery disease (CAD)—symptomatic angina or a history of myocardial infarction, bypass graft or coronary artery stenting; heart failure—ejection fraction <50% or the concurrent presence of exertional breathlessness and oral diuretic use; cerebrovascular disease—previous stroke or transient ischaemic attack.

The mean serum potassium of all measurements taken for the 3 months preceding the ECG was recorded. We were unable to address the speed of onset of hyperkalaemia in most cases due to the low frequency of routine blood sampling but did record peak potassium for each patient during the follow-up period.

The patients were followed up for a minimum of 12 months from the date the ECG was taken. The primary end point was cardiovascular mortality, and secondary end point was sudden death as defined by the United States Renal Data System [31].

ECG analysis

Two physicians who were blinded to the serum potassium independently reviewed the ECGs. Both had completed a local 3-day course on the advanced interpretation of ECGs, a requirement of which was to pass an examination on the interpretation of abnormal tracings.

The clinicians graded each ECG as having tented T-waves if they determined that the T-waves were peaked, shortened/symmetrical and with at least one precordial T-wave measuring ≥8 mm (1 SD above the mean T-wave amplitude in hyperkalaemia) [14, 32]. ECGs were classified as having tented T-waves if both clinicians determined that it had met these criteria. A second measurement of abnormal T-waves was made by comparing the ratio of the amplitude of the tallest precordial T-wave and the tallest R-wave on any precordial lead in the same cardiac cycle as the tallest T-wave. The ECG was considered abnormal if the T:R ratio was ≥0.75 (abbreviated in this study as TR75). This ratio was chosen as it was considered unlikely to ever represent a normal finding. This was based on the results of a previous study in 74 haemodialysis patients in which the T:R was 0.3 ± 0.01 (mean ± 1 standard deviation) [14]. Measurements were also taken of PR and QT interval, QRS complex duration, QRS and T-waves axes and for the presence of LVH using the Sokolow–Lyon Index [33].

Statistical analysis

Univariate and multivariate logistic regressions were used to determine which clinical features (including serum potassium) and ECG measurements were predictive of both tenting of T-waves and TR75. This included whether hyperkalaemic T-wave abnormalities were common in dialysis patients compared to transplant or pre-dialysis Stage 5 CKD. Cox regression analysis of the difference in outcome (cardiovascular death and sudden death) between hyperkalaemic patients with and without abnormal repolarization was performed while adjusting for other variables shown to influence T-wave changes and outcome.

Results

Patient selection

Three hundred and seventy-three patients were eligible for the study. Of these patients, 163 had a concurrent ECG and serum potassium measurement. Nineteen patients were excluded for having either complete left or right bundle branch block or a ventricular paced ECG rhythm, leaving 145 included in the final study cohort. The mean patient age was 58 years. Fifty-four per cent of patients were pre-dialysis, 43% on dialysis (mean time on dialysis = 2.5 ± 2.2 years) and 3% had a functioning transplant. Forty-four per cent of serum potassium readings were ≥6.0 mmol/L. The prevalence of CAD and diabetes mellitus was higher than that seen in the UK ESRD population according to the UK renal registry (44 versus 29% and 51 versus 24%, respectively) [34]. Patient characteristics are summarized in Table 1. There were 23 cardiovascular deaths and 9 sudden deaths during a mean follow-up of 3.8 ± 2.5 years. There were no acute deaths associated with hyperkalaemia.

T-wave changes: hyperkalaemia versus other abnormalities

Tenting of T-waves was more common in patients who met ECG voltage criteria for LVH than in hyperkalaemia...
and high TR75 compared to patients with normal perkalaemia than tenting. Serum calcium was 2.23 ± 0.18 versus 2.26 ± 0.17 mmol/L (P = 0.645).

In either case, the mean serum calcium was 2.20 ± 0.16 versus 2.27 ± 0.16 mmol/L in patients with inclusions or ex-smoker (%) 82
LVH (% Sokolow–Lyon criteria) 27
Diabetes (%) 51
Ethnicity (% Caucasian) 92
Age (years, mean ± SD) 58 ± 14
Gender (% male) 63
Modality (%) 54
Pre-dialysis 34
Peritoneal dialysis 9
Transplant 3
Serum potassium (mmol/L, % of total)
3.5–3.9 10.3
4.0–4.9 19.3
5.0–5.9 29.0
6.0–6.9 28.3
7.0–7.9 9.0
8.0–8.9 2.8
≥9.0 1.4

Though a positive TR75 became more likely as serum potassium increased, there were still significant numbers of patients with elevated potassium who did not exhibit this repolarization abnormality. One patient with a serum potassium >10.0 mmol/L had normal T-waves and 40% of patients with potassium ≥7.0 mmol/L had a normal ECG. There was no difference in the mean potassium over the preceding 3 months between those with normal and abnormal ECGs (5.8 ± 0.3 versus 6.1 ± 0.1 mmol/L, respectively, P = 0.295). The wide variation in the relationship between serum potassium and T-wave changes is shown in Figure 1.

Within the study cohort, there were eight patients who had two episodes of hyperkalaemia which were ±0.3 mmol/L of one another and in which there was T-wave tenting associated with one but not the other. In the ECG tracings with T-wave tenting, there was also a trend towards a longer QRS duration and shorter PR interval. None of the measurements in this analysis reached statistical significance, most likely due to the small number. This does suggest, however, that ECGs show other changes of hyperkalaemia even in the absence of tented T-waves. There was no significant difference in the measured parameters on performing a paired t-test. There had also been no intervening new cardiac diagnoses prior to the ECGs with tenting. Three of the eight patients had been pre-dialysed when the non-tenting ECG was taken and had started haemodialysis at the time of the second tenting ECG.

**T-wave changes and mortality**

As TR75 is more specific to hyperkalaemia than tenting, survival analysis was performed to assess the influence of this and other clinical variables as predictors of long-term risk for cardiovascular events and sudden death (Table 3). Age, being on dialysis, and time on dialysis were independent predictors of cardiovascular events. A history of CAD was not, though the P-value was 0.069 and hazard ratio (HR) was 2.13 for patients with CAD compared to those without. This is therefore likely to be an effect of study power. Figure 2 shows the event-free survival curve adjusted for age, co-morbidities, dialysis, dialysis vintage and serum potassium, separated for the presence or absence of TR75. For sudden death, the only independent predictor was TR75 (HR = 8.33, P = 0.21). There was no difference in the acute or time-averaged serum potassium or in any other clinical covariate (Table 3). Figure 3 shows the cumulative risk for sudden death in patients with and without TR75, adjusted for the same variables as Figure 2. As shown by the HR above, there is a clear independent prognostic risk for the presence of tall T-waves in hyperkalaemia.

**Discussion**

**Clinical predictors of T-wave tenting**

In this study of 145 patients with ESRD, hyperkalaemia was not significantly predictive of T-wave tenting. Instead,
age was the strongest predictor. Younger patients are more likely to show tenting, probably because T-wave amplitude decreases with age [35]. Hence, the absence of tenting in older patients may be a false-negative result if looking for hyperkalaemic ECG changes. Patients with diabetes were similarly less likely to show tenting. The mean T-wave amplitude for diabetic patients was 7.0 versus 8.4 mm in non-diabetic subjects (P = 0.021), despite there being no difference in serum potassium readings. The reason for this is not clear. Diabetes has been shown to affect other measurements of repolarization [36, 37], but not specifically T-wave amplitude other than in one study of induced hypoglycaemia in 16 subjects [38].

This likely reason that T-wave tenting is poorly predictive of hyperkalaemia is that it is a common finding in patients with normal potassium and often absent in cases of hyperkalaemia. LVH and acute coronary ischaemia are also known to cause acute T-wave tenting [13]. Tenting was more common in LVH than hyperkalaemia in this study. In the absence of a baseline ECG for comparison, one cannot determine whether T-wave tenting is a new phenomenon in hyperkalaemia. This argues that routine baseline ECGs are of potential value in the care of patients with ESRD.

### Table 2. Measured variables and their association with either T-wave tenting or a T:R ratio of ≥ 0.75 (TR75)*

<table>
<thead>
<tr>
<th>Factor</th>
<th>T-wave tenting</th>
<th>TR75</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present</td>
<td>Factor value</td>
</tr>
<tr>
<td>Age (years ± SD)</td>
<td>Yes</td>
<td>54.1 ± 13.5</td>
</tr>
<tr>
<td>No</td>
<td>60.0 ± 14.3</td>
<td>0.139</td>
</tr>
<tr>
<td>CAD (% yes)</td>
<td>Yes</td>
<td>25.0</td>
</tr>
<tr>
<td>No</td>
<td>26.8</td>
<td>0.139</td>
</tr>
<tr>
<td>Heart failure (% yes)</td>
<td>Yes</td>
<td>35.4</td>
</tr>
<tr>
<td>No</td>
<td>58.3</td>
<td>0.106</td>
</tr>
<tr>
<td>Diabetes (% yes)</td>
<td>Yes</td>
<td>35.4</td>
</tr>
<tr>
<td>No</td>
<td>58.3</td>
<td>0.106</td>
</tr>
<tr>
<td>LVH (% yes)</td>
<td>Yes</td>
<td>25.0</td>
</tr>
<tr>
<td>No</td>
<td>26.8</td>
<td>0.139</td>
</tr>
<tr>
<td>Smoker (% current/ex-smoker)</td>
<td>Yes</td>
<td>82.8</td>
</tr>
<tr>
<td>No</td>
<td>84.5</td>
<td></td>
</tr>
<tr>
<td>Ethnicity (% Caucasian)</td>
<td>Yes</td>
<td>97.9</td>
</tr>
<tr>
<td>No</td>
<td>89.7</td>
<td></td>
</tr>
<tr>
<td>Gender (% male)</td>
<td>Yes</td>
<td>72.9</td>
</tr>
<tr>
<td>No</td>
<td>41.2</td>
<td></td>
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<tr>
<td>Serum K+ (mmol/L)</td>
<td>Yes</td>
<td>5.85 ± 1.35</td>
</tr>
<tr>
<td>No</td>
<td>5.56 ± 1.35</td>
<td></td>
</tr>
<tr>
<td>Mean K+ (mmol/L)</td>
<td>Yes</td>
<td>5.46 ± 0.85</td>
</tr>
<tr>
<td>No</td>
<td>5.28 ± 0.67</td>
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</tr>
<tr>
<td>δK+ (mmol/L)</td>
<td>Yes</td>
<td>0.41 ± 0.79</td>
</tr>
<tr>
<td>No</td>
<td>0.26 ± 0.99</td>
<td></td>
</tr>
<tr>
<td>Serum calcium (mmol/L)</td>
<td>Yes</td>
<td>2.20 ± 0.16</td>
</tr>
<tr>
<td>No</td>
<td>2.27 ± 0.16</td>
<td></td>
</tr>
<tr>
<td>Modality (% dialysis)</td>
<td>Yes</td>
<td>35.4</td>
</tr>
<tr>
<td>No</td>
<td>45.4</td>
<td></td>
</tr>
<tr>
<td>Time on dialysis (years)</td>
<td>Yes</td>
<td>2.62 ± 2.30</td>
</tr>
<tr>
<td>No</td>
<td>2.59 ± 2.40</td>
<td></td>
</tr>
<tr>
<td>T-wave axis (O)</td>
<td>Yes</td>
<td>60.9 ± 38.0</td>
</tr>
<tr>
<td>No</td>
<td>70.1 ± 59.9</td>
<td></td>
</tr>
<tr>
<td>QRS—T axis (O)</td>
<td>Yes</td>
<td>3.8 ± 32.1</td>
</tr>
<tr>
<td>No</td>
<td>5.1 ± 34.6</td>
<td></td>
</tr>
<tr>
<td>QTc interval (ms)</td>
<td>Yes</td>
<td>416.6 ± 32.2</td>
</tr>
<tr>
<td>No</td>
<td>418.6 ± 36.8</td>
<td></td>
</tr>
</tbody>
</table>

*Sig, significance; mean K+, mean potassium values in preceding 3 months; δK+, difference between peak and mean potassium values; QRS – T axis, difference between the QRS axis and T-wave axis on ECG.

*Significant at the level of 0.05 on univariate analysis.

#Significant at the level of 0.05 on multivariate analysis

![Fig. 1. Variation in the relationship between serum potassium and the amplitude of the tallest T-wave relative to the tallest R-wave.](https://academic.oup.com/ndt/article-abstract/28/1/99/1825979/14-January-2019)
This study found no other clinical or biochemical correlates with T-wave changes. One previous study showed an inverse relationship between serum calcium and the height of T-waves. The authors hypothesized that in this setting, relative hypercalcemia was cardioprotective from the effects of hyperkalemia and so hyperkalemic ECG changes did not manifest [14]. Relative hypercalcemia reduces the effect of hyperkalemia on the resting membrane potential of ventricular myocardium [39]. The presence of acidosis may also cause repolarization changes, independent of the effect on potassium handling [40].

Ultimately, the only conclusion to be drawn from the first aim of this study is that age is the strongest predictor of T-wave tenting. It is likely that the influence of the other covariates assessed was not seen because of study power. Indeed, these other factors are likely to explain why two near identical potassium levels in the same patient at different times can result in different repolarization patterns on ECG.

In this study, hyperkalemia was associated with an increase in the T-wave amplitude relative to the R-wave amplitude, but the variability in T:R was very large for similar serum potassium readings. It has previously been shown that patients with CKD or chronic hyperkalemia develop compensatory mechanisms that restore myocardial membrane potential to normal, even when the patient is hyperkalemic [41–43]. Also, dialysis patients are reported to have a tolerance of hyperkalemia, due to a relatively slow rate of increase in serum potassium compared to the general population, when an excess of potassium is ingested [17, 30]. This goes some way to explain the absence of T-wave tenting where it may have been expected [8]. However, this study and others have noted normal ECGs despite the presence of a serum potassium of >9.0 mmol/L [15, 44]. Mean serum potassium levels over the previous 3 months were used as a surrogate of chronicity of hyperkalemia. This did not influence the tendency to ECG changes. The variability of ECG

<table>
<thead>
<tr>
<th>Variable</th>
<th>Major cardiovascular event or death</th>
<th>Sudden Death</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (per year)</td>
<td>0.011* 1.03 1.01–1.06</td>
<td>0.731 1.01 1.01–1.06</td>
</tr>
<tr>
<td>CAD</td>
<td>0.069 2.13 0.94–4.78</td>
<td>0.099 6.67 0.69–50.00</td>
</tr>
<tr>
<td>Heart failure</td>
<td>0.237 0.53 0.18–1.52</td>
<td>0.198 0.21 0.02–2.27</td>
</tr>
<tr>
<td>CVA/TIA</td>
<td>0.388 1.67 0.52–5.56</td>
<td>0.651 1.63 0.19–14.29</td>
</tr>
<tr>
<td>Diabetes</td>
<td>0.381 1.43 0.71–2.94</td>
<td>0.477 2.78 0.52–16.67</td>
</tr>
<tr>
<td>LVH on ECG</td>
<td>0.364 1.33 0.72–2.43</td>
<td>0.587 0.63 0.12–3.33</td>
</tr>
<tr>
<td>On dialysis</td>
<td>0.029* 2.17 1.08–4.35</td>
<td>0.119 4.17 0.69–25.00</td>
</tr>
<tr>
<td>Dialysis (per year)</td>
<td>0.002* 1.31 1.11–1.56</td>
<td>0.805 1.06 0.68–1.66</td>
</tr>
<tr>
<td>K⁺ (per mmol/L)</td>
<td>0.217 0.87 0.70–1.09</td>
<td>0.197 0.66 0.35–1.24</td>
</tr>
<tr>
<td>TR75</td>
<td>0.621 1.20 0.56–2.63</td>
<td>0.021* 8.33 1.39–49.97</td>
</tr>
</tbody>
</table>

*aSignificance; TR75, ration of T-wave to R-wave amplitude of ≥0.75.
*Significant at the level of α = 0.05.
manifestations in hyperkalaemic dialysis patients suggests that, if this is the case, it is not a universal phenomenon.

The rate of change of serum potassium will also influence the effect of elevated potassium on the action potential. This means that relative changes in potassium are important and not just absolute serum values. In the animal models, more rapid infusion of potassium leads to greater effect on myocardial membranes [18, 19, 45]. The present study was unable to measure the rate of onset of hyperkalaemia in participating patients. Furthermore, without a direct measure of membrane potential, fully understanding the relationship between hyperkalaemia and ECG findings is difficult. This is a shortcoming of clinical observational studies such as this. Finally, it cannot be ruled out that different ECG changes for the same potassium reading may occasionally be due to erroneous blood sampling. Haemolysis, leucocytosis, thrombocytosis and inflammation can produce pseudohyperkalaemia [46].

Tentung versus T-wave: R-wave as a measure of hyperkalaemia

T-wave tenting was neither specific to nor a frequent finding in hyperkalaemia. This follows the pattern seen in other studies where between 27 and 46% of hyperkalaemic patients had T-wave abnormalities [9, 14, 47]. The difference in prevalence between studies may reflect the different definitions of tenting used in each. Wrenn et al. [20] found that the sensitivity and specificity of tenting were 34–43 and 85–86%, respectively, with some interpreter differences. These are not dissimilar to the findings presented above.

The relationship between the T-waves and QRS complex amplitudes is a less subjective measure of ECG change than tenting. This also removes some of the bias introduced by the variability in T-waves noted with age and in the variation in R-wave amplitude (and so subsequent T-wave amplitude) associated with LVH. This result is at variance with a previous study which did not show any statistically significant difference in the T:R wave ratio between patients with a serum potassium $>5.5$ mmol/L (mean ratio = 2.8) versus $\leq 5.5$ mmol/L (mean ratio = 1.9, $P = 0.37$) [14]. Using this measure improves the specificity of using repolarization changes as a marker of hyperkalaemia, but it becomes less sensitive. Ultimately, neither tenting nor T:R are adequately specific or sensitive to be useful as a prognostic indicator in the acute setting. While such measures are useful in the experimental setting such as this, they do not provide suitable diagnostic capabilities when faced with an elevated serum potassium in an individual patient. Also, because there are many competing factors in whether a patient develops ECG changes in hyperkalaemia, the absence of abnormal T-waves should not be used as a rationale to avoid treating elevated serum potassium. Instead, their presence is an indicator of clinical urgency to do so.

T-wave changes and cardiovascular outcome

Although this study does not support the usefulness of ECG-derived T-wave tenting as a clinical tool in guiding acute management of hyperkalaemia, it does suggest that the presence versus absence of T-wave changes in this setting may provide important longer-term prognostic information for patients with ESRD. An aim of the study was to determine whether hyperkalaemia-associated T-wave changes were reflective of a more general pathological process of abnormal repolarization which may leave patients at risk of significant arrhythmia. It has been established that dialysis patients tend to have a prolonged time-corrected QT interval ($\text{QT}_{c}$) relative to the general population [25]. Dialysis itself can also directly further prolong the $\text{QT}_{c}$ [48], and this can also be seen in rapid outward shifts in potassium when using low potassium dialysate. T-wave alternans have also been shown to be affected by dialysis [26]. Both are markers of aberrant repolarization and are associated with increased risk of sudden death. Abnormal repolarization can lead to ventricular arrhythmia as it is a time of rapid shifts in the membrane potential of conducting tissue [27, 28]. In the general population, other repolarization abnormalities such as the presence of J-waves are associated with ventricular arrhythmia [27]. Additionally, ‘cardiac arrest, cause unknown’ or confirmed arrhythmic death account for $26\%$ of deaths in dialysis patients and occur at a rate of at least $56$ events per $1000$ patient-years [7]. Clearly, sudden death is an important area of cardiovascular risk in ESRD which must be addressed and abnormal repolarization is a potential trigger to this.

Hyperkalaemic arrhythmic death is thought to be most often due to depolarization changes and subsequent bradydysrhythmia/asystole. It is for this reason that T-wave changes are not directly predictive of acute arrhythmic risk. The third aim of this study was to investigate long-term risk in patients who have abnormal T-waves versus those who do not. This has been achieved in showing that tall T-waves predict long-term risk of sudden death when adjusted for other cardiovascular risk factors. What is needed now is a means to translate this into a clinically useful tool. Perhaps in the future, clinicians can use ECG as well as serum biochemistry to determine appropriate dialysate electrolyte concentrations. Adjusting dialysate potassium and calcium to achieve better membrane stability, measured indirectly by the conformity of T-wave amplitude in serial ECGs, may provide some long-term cardiovascular protection.

Acknowledgements. This work was made possible by the patients and staff from the Department of Renal Medicine at Salford Royal Hospital, and the department’s Renal Charitable Fund.

Conflict of interest statement. None declared.

(See related article by Welch et al. Hyperkalemia: getting to the heart of the matter. Nephrol Dial Transplant 2013; 28: 15–16.)

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Received for publication: 27.9.2011; Accepted in revised form: 14.1.2013