Clinical Study

Potential of Dried Blood Self-Sampling for Cyclosporine C2 Monitoring in Transplant Outpatients

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Background. Close therapeutic drug monitoring of Cyclosporine (CsA) in transplant outpatients is a favourable procedure to maintain the long-term blood drug levels within their respective narrow therapeutic ranges. Compared to basal levels (C0), CsA peak levels (C2) are more predictive for transplant rejection. However, the application of C2 levels is hampered by the precise time of blood sampling and the need of qualified personnel. Therefore, we evaluated a new C2 self-obtained blood sampling in transplant outpatients using dried capillary and venous blood samples and compared the CsA levels, stability, and clinical practicability of the different procedures.

Methods. 55 solid organ transplant recipients were instructed to use single-handed sampling of each 50 μL capillary blood and dried blood spots by finger prick using standard finger prick devices. We used standardized EDTA-coated capillary blood collection systems and standardized filter paper WS 903. CsA was determined by LC-MS/MS. The patients and technicians also answered a questionnaire on the procedure and sample quality.

Results. The C0 and C2 levels from capillary blood collection systems (C0 [ng/mL]: 114.5 ± 44.5; C2: 578.2 ± 222.2) and capillary dried blood (C0 [ng/mL]: 175.4 ± 137.7; C2: 743.1 ± 368.1) significantly (P < .01) correlated with the drug levels of the venous blood samples (C0 [ng/mL]: 97.8 ± 37.4; C2: 511.2 ± 201.5). The correlation at C0 was ρ_cap.-ven. = 0.749, and ρ_dried blood-ven = 0.432; at C2: ρ_cap.-ven. = 0.861 and ρ_dried blood-ven = 0.711. The patients preferred the dried blood sampling because of the more simple and less painful procedure. Additionally, the sample quality of self-obtained dried blood spots for LC-MS/MS analytics was superior to the respective capillary blood samples. Conclusions. C2 self-obtained dried blood sampling can easily be performed by transplant outpatients and is therefore suitable and cost-effective for close therapeutic drug monitoring.

1. Introduction

Despite the upcoming new drugs, Cyclosporine A (CsA) is still one of the most important immunosuppressants in solid organ transplantation. Due to its narrow therapeutic range, the high intra- and interindividual variability of absorption and metabolism, and the need of highly compliant daily administration, long-term accurate and frequent monitoring of CsA concentrations is pivotal to avoid graft rejection at underdose and nephrotoxicity at overdose. Since the variation in CsA exposure is greatest during the absorption phase in the first 4- to 12-hour post-dose, the determination of the pharmacokinetic area under the curve (AUC0–4, resp., AUC0–12) [1, 2] provides an adequately precise measure of drug exposure. However, AUC determination requires multiple blood samplings; it is uncomfortable for the patient, expensive, and difficult to perform in a routine clinical setting. The commonly performed measurement of predose CsA concentrations (C0) is, in contrast, less applicable for CsA pharmacokinetic monitoring since it does not perfectly correlate with CsA exposure as determined by AUC analysis, and it does not predict nonoccurrence of graft rejection [2]. In contrast, the CsA C2 (2 hours post-dose) peak concentration highly correlates with AUC. Therefore, CsA
C₂ levels have been initially described as the optimal single-time point marker for AUC [3–5]. However, C₂ monitoring bears some practical difficulties due to the narrow time frame of ±15 min for blood sampling performed by qualified medical personnel. Hence, it is reasonable to shift the sampling work to capable patients who can profit from the enhanced sampling accuracy, even when they stay at home [6]. Novel mass spectrometric-based analytical methods for the determination of CsA only require small volumes of EDTA-whole blood (≤50 μL). Therefore, self-sampling systems like capillaries or dried blood spots become applicable for transplant patients. Our paper aimed at the evaluation and comparison of feasible CsA C₂ self-sampling procedures for capillary EDTA and dried blood in patients after solid organ transplantation with respect on reproducibility, accuracy, sampling quality, and particularly the patient-related practicability and acceptance.

2. Methods and Materials

2.1. Patients. 55 solid organ transplant recipients (42 renal, 2 combined renal/pancreas, 11 liver transplants; m/f 37/18; age 52 years ±10) from the outpatient clinic of the Transplant Center of the University Hospital of Leipzig were recruited for this paper. All patients received daily CsA dosing (120–500 mg/d), 42 patients additionally MMF and were on steady state medication at least three months after transplantation.

The study was approved by the local ethics committee and fulfilled all requirements of the latest amendment of the Helsinki declaration. All patients declared their informed consent.

2.2. Study Design. The study included three visits, number 1 and number 3 at the clinic, number 2 at home. Visit number 1 comprised patients recruitment and training for standardized self-sampling of capillary EDTA-whole blood and dried blood, venous blood drawing, and exemplary sampling of capillary blood and dried blood, as well as delivering a prepared kit for home sampling. At visit number 2, about four weeks after visit number 1, patients obtained capillary blood and dried blood at home and shipped it to the laboratory using the prepared kits. Visit number 3 consisted of venous sampling and supervised capillary self-sampling as well as filling out the questionnaire. Sampling quality of all visits was controlled before analysis using a standardized checklist. Blood specimens were assessed in the lab. by the technicians with respect to sample quality.

2.3. Material. For capillary sampling we used mechanical finger-prick devices (Accu-Check Softclix Pro, Roche Diagnostics, Mannheim, Germany), EDTA-coated capillary vials (Microvette No 20.1278, Sarstedt, Nümbrecht, Germany), and specimen collection filter paper (Whatman & Schüll No 903, Whatman, Middlesex, UK). For dried blood spots, capillary EDTA-blood was dropped on the filter paper and air dried thereafter for at least 2 h. Systems for venous blood sampling (EDTA Monovette and Multify needle sets) were obtained from Sarstedt (Nümbrecht, Germany). Postpaid shipping kits pursuant UNO “UN 3373” norm were prepared for the patients.

2.4. Analytical Methods. We determined CsA levels by liquid chromatography tandem mass spectrometry (LC-MS/MS) in venous and capillary EDTA-blood (50 μL sample volume) as previously described [7]. For the CsA analysis in dried blood a 4 mm diameter spot (corresponding blood volume 4 μL) was eluted with 100 μL methanol containing Cyclosporine D (CsD) as internal standard. After stirring (20 min), CsA measurements were performed using 35 μL of the supernatant.

2.5. Patient Questionnaire. The patient-related practicability was assessed by the following questions: Could you draw capillary blood without help? If not, when did you need help? Do you prefer capillary or venous sampling? Do you prefer capillary EDTA vials or specimen collection filter paper? Did you encounter problems shipping the samples?

2.6. Technician Questionnaire. Sampling quality was assessed by the following criteria: sample volume, observed clotting, proper filter, and paper dropping.

2.7. Statistics. Statistical analyses were performed using MedCalc (Mariakerke, Belgium), SPSS (Chicago, USA), and R [8] with the latticist package [9]. For correlation analysis, Spearman’s ρ coefficient was calculated. Significance of differences between groups was computed with the Mann-Whitney-U-test [*(P < .05); **(P < .01)]
3. Results

3.1. CsA Concentrations in Capillary Blood Correlate with Venous Levels. CsA C0 and C2 concentrations in venous blood correlated significantly with concentrations obtained from capillary EDTA blood and to a lesser but also significant extent with CsA concentrations derived from dried blood spots (Table 1).

3.2. CsA Is Stable in Dried Blood Spots at 8°C. 18 capillary dried blood samples with and without EDTA-stabilizing were stored at 8°C and 20°C for 2, 4, 6, 12, and 24 hours and analyzed thereafter (Figure 1). Samples were stable up to at least 12 hours, a significant difference (P = .013) in stability between cooled and noncooled dried blood spots arose, though, only at the 24 h time point. The 24 h total decrease in CsA concentrations was significant in both groups (cooled: P < .05; noncooled: P < .001). While EDTA failed to exert stabilizing effects in dried blood spots, neither did we find remarkable decomposition of CsA in capillary EDTA blood samples nor is it mentioned in the recent literature [10, 11].

3.3. CsA Concentrations Depend on the Sample Material. CsA measurement in capillary blood resulted in significantly higher CsA C0 and C2 levels compared to venous blood. Dried blood spots yielded the highest concentrations and variance (Table 2 and Figure 2). Based on the high correlation to the venous concentrations and the linearity of increase, the discrepancy might be overcome by the introduction of a correction factor. We found a significant (P = .010) difference between CsA C2 concentrations in

Table 1: Correlations of venous and capillary CsA concentrations.

<table>
<thead>
<tr>
<th>Visit</th>
<th>Correlation</th>
<th>C0</th>
<th>C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>VE–CE</td>
<td>0.749**</td>
<td>0.854**</td>
</tr>
<tr>
<td></td>
<td>VE–CDB</td>
<td>0.432**</td>
<td>0.753**</td>
</tr>
<tr>
<td></td>
<td>CE–CDB</td>
<td>0.521**</td>
<td>0.642**</td>
</tr>
<tr>
<td>(2)</td>
<td>CE–CDB</td>
<td>0.498**</td>
<td>0.835**</td>
</tr>
<tr>
<td></td>
<td>VE–CE</td>
<td>0.861**</td>
<td>0.861**</td>
</tr>
<tr>
<td></td>
<td>VE–CDB</td>
<td>0.383*</td>
<td>0.711**</td>
</tr>
<tr>
<td></td>
<td>CE–CDB</td>
<td>0.274</td>
<td>0.652**</td>
</tr>
</tbody>
</table>

Correlations as Spearman’s ρ; *(P < .05); **(P < .01); Venous EDTA blood VE; Capillary EDTA blood CE; Capillary Dried Blood CDB.

Table 2: Absolute mean venous and capillary CsA concentrations of all patients at all visits.

<table>
<thead>
<tr>
<th>Visit</th>
<th>Mat.</th>
<th>C0 (μg/L)</th>
<th>C2 (μg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>VE</td>
<td>95.1 ± 28.7</td>
<td>586.0 ± 247.2</td>
</tr>
<tr>
<td></td>
<td>CE</td>
<td>117.4 ± 49.0</td>
<td>710.3 ± 386.5</td>
</tr>
<tr>
<td></td>
<td>CDB</td>
<td>171.4 ± 92.6</td>
<td>756.2 ± 378.6</td>
</tr>
<tr>
<td>(2)</td>
<td>CE</td>
<td>115.7 ± 99.5</td>
<td>507.4 ± 259.7</td>
</tr>
<tr>
<td></td>
<td>CDB</td>
<td>146.5 ± 83.2</td>
<td>621.9 ± 359.1</td>
</tr>
<tr>
<td>(3)</td>
<td>VE</td>
<td>97.8 ± 37.4</td>
<td>511.2 ± 201.5</td>
</tr>
<tr>
<td></td>
<td>CE</td>
<td>114.5 ± 44.5</td>
<td>578.2 ± 222.2</td>
</tr>
<tr>
<td></td>
<td>CDB</td>
<td>175.4 ± 137.7</td>
<td>743.1 ± 368.1</td>
</tr>
</tbody>
</table>

Absolute CsA C0 and C2 concentrations at all visits; Venous EDTA-Blood VE; Capillary EDTA blood CE; Capillary Dried Blood CDB.
capillary blood when comparing the withdrawals performed by a physician (visit 1) and by the patient at home (visit 2) in renal transplant recipients, probably due to the awkward handling of the tubes. In liver transplant recipients, there was a barely significant \( P = .043 \) difference between the CsA C2 concentrations from self-obtained dried blood samples at visit 2 and from samples under supervision drawn at the transplant center at visit 3. We found also a slight decrease \( P = .048 \) of CsA C2 concentrations in EDTA blood from visit 1 to visit 3 in renal transplant recipients (Figure 2).

### 3.4. Self-Sampling of Capillary Blood Is Feasible and Applicable for Transplant Patients

All patients considered themselves as sufficiently informed to perform capillary sampling at home. 91% of the patients were able to obtain blood without help. 61% preferred capillary sampling to venous sampling, 30% were undecided, 65% versus 18% preferred capillary dried blood to capillary EDTA sampling due to facilitated handling. All patients drew capillary blood from the finger pad, 13% encountered shipping problems caused by the size of the shipping box pursuant to UN 3373. The sample quality of the capillary samples was evaluated by the lab technicians using a predefined checklist. 83% of the dried blood spots and 73% of the self-obtained capillary EDTA samples were adequate, 16% versus 23% of the samples provided insufficient material, and 1% versus 4% was coagulated, respectively.

### 4. Discussion

We observed adequate correlation of \( C_0 \) and \( C_2 \) levels derived from capillary dried whole EDTA blood and the capillary EDTA blood with the corresponding venous blood samples as also stated by Keevil and Merton for the latter [10–12]. The weaker correlation of CsA \( C_0 \) and \( C_2 \) levels measured in dried blood might be caused by the small sample volume used for analysis (4 μL versus 50 μL EDTA blood), which results in effective CsA concentrations below 10 ng/mL in the processed sample. In this low concentration range CsA contaminations of the internal standard CsD interfere with the measurement [13]. Additionally, the blood volume in the 4 mm dried blood spot varies depending on the individual hematocrit. Moreover, chromatographic effects of CsA (radial concentration gradient and increase of variance) in the filter paper were observed [14]. Therefore, dried blood should only be punched from the center of the blood spot to restrain preanalytical variance.

Self-sampling may become an alternative of venous function and nephrotoxicity in renal and nonrenal transplant recipients and might point at a still not sufficiently informed patients. Together with the linearity of the increase, which may be adjusted by the introduction of correction factors, capillary blood (EDTA blood or dried blood) was proved to be an appropriate medium for steady-state CsA monitoring in solid organ transplant patients [10–12].

Additionally, capillary blood samples could also be used to determine further immunosuppressant drugs, ranging from tacrolimus, sirolimus, and everolimus to MMF [6, 15, 16] or even creatinine as a correlate of renal transplant function and nephrotoxicity in renal and nonrenal transplant recipients [12] in a single sample, which renders the method favorable for pediatric transplant patients, where sampling is frequently difficult and cumbersome. From an economical point of view, self-sampling at home can save expenses for qualified ward personnel and travelling costs to the outpatient wards. Additionally, the patient’s CsA monitoring results might be already available when the patient undergoes his routine checkup.

Comparing our results for CsA \( C_2 \) monitoring using capillary EDTA blood with previous studies reveals analogue
correlations with the results of the venous “gold standard” method [10, 11]. However, there is only one publication by Azevedo et al. investigating the feasibility of CsA C2 monitoring in dried blood, demonstrating a comparable correlation of \( r = 0.81 \) for radioimmunological assays of dried blood CsA C2 concentrations and routine CsA C2 determinations from venous whole blood though applying a five times higher dried blood volume of 20 \( \mu L \) [17].

Apart from the aforementioned advantages of CsA C2 monitoring using capillary blood, there are several limitations to be considered. The main constraint is the small sample volume, especially favoured in pediatric patients, restricting the number of parameters determined simultaneously and demanding multiparametric methods. Moreover, the capillary sample material is not suitable for many, in particular for the hemolysis-sensitive parameters. The finite stability of the analytes in dried blood might as well interfere with the clinical use of dried blood monitoring as the elaborate analytical methods.

Taking the above-mentioned factors into account, CsA self-monitoring using capillary EDTA blood or capillary dried blood spots is feasible and comfortable for transplant patients—even at home—with respect on sufficient comparability to venous blood, accuracy for clinical use, sampling quality, and patient-related practicability.

5. Conclusion

C2 self-obtained blood sampling using EDTA-stabilized capillary and dried blood spots can be easily performed by transplant recipients and results in CsA measurements acceptable for steady-state monitoring. The type of blood sampling influences the respective CsA levels. However, the patient-related intraprocedural variances of CsA measurements are still appropriate for C2 monitoring in clinical practice. Therefore, dried blood self-sampling is suitable for Cyclosporine C2 monitoring in transplant outpatients.

**Abbreviations**

- CsA: Cyclosporine A
- LC-MS/MS: Liquid chromatography/-tandem mass spectrometry
- MMF: Mofetil Mycophenolate
- EDTA: Ethylene diamine tetra-acetate
- AUC: Area under the curve
- C0: CsA baseline concentration
- C2: CsA 2-hour post-dose concentration

**Disclosures**

All authors declare that no conflict of interest interferes with the study. The results presented in this paper have not been published previously in whole or part, except in abstract format. This paper was supported by a research grant from Novartis to JT and HW. The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

**Short Summary**

CsA self-monitoring using dried blood spots is feasible and comfortable for transplant patients—even at home—with respect on sufficient comparability to venous blood, accuracy for clinical use, sampling quality, and patient-related practicability.

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**References**


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