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Electronic monitoring of treatment adherence and validation of alternative adherence measures in tuberculosis patients: a pilot study

Jossy van den Boogaard, Ramsey A Lyimo, Martin J Boeree, Gibson S Kibiki & Rob E Aarnoutse

Objective To assess adherence to community-based directly observed treatment (DOT) among Tanzanian tuberculosis patients using the Medication Event Monitoring System (MEMS) and to validate alternative adherence measures for resource-limited settings using MEMS as a gold standard.

Methods This was a longitudinal pilot study of 50 patients recruited consecutively from one rural hospital, one urban hospital and two urban health centres. Treatment adherence was monitored with MEMS and the validity of the following adherence measures was assessed: isoniazid urine test, urine colour test, Morisky scale, Brief Medication Questionnaire, adapted AIDS Clinical Trials Group (ACTG) adherence questionnaire, pill counts and medication refill visits.

Findings The mean adherence rate in the study population was 96.3% (standard deviation, SD: 7.7). Adherence was less than 100% in 70% of the patients, less than 95% in 21% of them, and less than 80% in 2%. The ACTG adherence questionnaire and urine colour test had the highest sensitivities but lowest specificities. The Morisky scale and refill visits had the highest specificities but lowest sensitivities. Pill counts and refill visits combined, used in routine practice, yielded moderate sensitivity and specificity, but sensitivity improved when the ACTG adherence questionnaire was added.

Conclusion Patients on community-based DOT showed good adherence in this study. The combination of pill counts, refill visits and the ACTG adherence questionnaire could be used to monitor adherence in settings where MEMS is not affordable. The findings with regard to adherence and to the validity of simple adherence measures should be confirmed in larger populations with wider variability in adherence rates.

Introduction

Non-adherence to treatment for tuberculosis is a major barrier to global tuberculosis control. To ensure adherence to treatment by tuberculosis patients, the direct observation of treatment by a trained supervisor is recommended. Initially, such directly observed treatment (DOT) was provided in health-care facilities only, but because of workload demands, several countries have started to involve community members in the provision of DOT. Studies have shown that community-based DOT is a cost-effective strategy that yields treatment outcomes similar to those obtained with facility-based DOT. However, community-based DOT has been criticized for being beyond the control of health-care providers and hence conducive to self-administered (unsupervised) treatment and non-adherence. The actual degree of adherence by patients on community-based DOT has not yet been assessed. Measuring adherence is difficult because most available direct and indirect measures have limitations. Direct adherence measures, such as tests to measure drug levels in plasma or urine, cover brief medication intake periods only. Indirect measures, such as pill counts and self-report questionnaires, cover longer periods but assume rather than prove the patient’s actual medication intake. A sophisticated indirect adherence measure is the Medication Event Monitoring System (MEMS). MEMS medication bottles contain a microelectronic chip that registers the date and time of every bottle opening. Assuming that bottle openings represent medication intake, MEMS provides a detailed profile of the patient’s adherence behaviour. MEMS is currently regarded as the gold standard to measure adherence. It has been used as such in a wide range of studies on adherence to antihypertensive and lipid-lowering therapy, therapy for neurologic and psychiatric disorders, post-transplantation immunosuppressive therapy and antiretroviral therapy. Few studies report on the use of MEMS to monitor adherence to tuberculosis treatment. Because of the high cost involved, MEMS is not feasible for use in routine practice in most settings with a high tuberculosis burden but could be used as a reference standard to validate simple and affordable measures that can be used in patients on community-based DOT.

In this pilot study, we used MEMS to: (i) describe adherence rates among Tanzanian tuberculosis patients on community-based DOT and (ii) determine the validity of several direct and indirect adherence measures of potential use in resource-limited settings.

Methods

Study setting

The study was conducted in the Kilimanjaro region of the United Republic of Tanzania, where the annual tuberculosis case notification rate is 178 per 100 000 population. The national tuberculosis programme empowers patients to choose between community- and facility-based DOT. Most patients opt for community-based DOT and those on facility-based DOT are mostly inpatients. Patients on community-based DOT have to select a treatment supporter.
from their community (usually a relative or spouse) who is instructed on how to provide daily DOT at home. Patients on community-based DOT are supposed to collect their medication once a week in the first two months of treatment and once every two weeks in the remaining four months. They should return medication blisters for pill counts and their clinic attendance is registered.

Study design and procedures

This was a longitudinal pilot study in which treatment adherence among 50 patients on community-based DOT was monitored by MEMS throughout treatment. MEMS was used as a gold standard to validate several other adherence measures (single and in combinations) in this patient group. The adherence measures were selected for their applicability in the Tanzanian setting and included an isoniazid (INH) urine test, a urine colour test for rifampicin, the Brief Medication Questionnaire (BMQ), the Morisky scale, an adapted version of the AIDS Clinical Trials Group (ACTG) adherence questionnaire, pill counts and clinic attendance for medication refills.

The participants were recruited between February and May 2010 from one rural hospital, one urban hospital and two urban health centres. Considering the pilot nature of our study, we chose to enrol 50 patients only. Adult outpatients who consecutively presented at one of the study sites with newly diagnosed tuberculosis and who had chosen community-based DOT were eligible to participate. Eligible patients were informed about the study procedures by trained clinic staff and asked to sign an informed consent form. They were told that their tuberculosis medication would be provided in a medication bottle with a microelectronic chip that registers every bottle opening. They were asked not to use the MEMS bottle for other medication, to open it only to take out medication, and to bring the bottle to every medication refill visit. Patients were informed that they would be under routine treatment and care.

Drug dispensing nurses were responsible for providing patients with medication. Medication refill visits were conducted in accordance with routine practice, except that the medication blisters were cut into pieces to make them fit in the MEMS bottle. The nurses registered the dates of the patients’ clinic visits for medication refills and the number of tablets remaining at each visit. During the visits in weeks 4, 8, 12 and 16, the procedures deviated from routine practice. At these visits, patients submitted a sample of urine and were asked to fill out the BMQ and Morisky scale (in weeks 4, 8 and 12) or the ACTG adherence questionnaire (in week 16). At completion of treatment, the patients filled out a questionnaire about their experience with the use of MEMS bottles.

Treatment adherence measures

Medication Event Monitoring System

MEMS medication bottles (250-ml containers with a 38-mm MEMS 6 TrackCap, AARDEX Ltd, Sion, Switzerland) were used by all participants throughout treatment. MEMS data were used to calculate adherence rates (by dividing the number of days on which at least one bottle opening was registered by the total number of monitored days and multiplied by 100) and to differentiate between adherent and non-adherent patients for validation of the other adherence measures. For the latter purpose, commonly used adherence rate cut-off values of 100%, 95% and 80% were applied.

Isoniazid urine test

The isoniazid urine test or IsoScreen test (GFC Diagnostics Ltd, Bicester, England) is based on the Arkansas method for the detection of INH in urine and supplied in a ready-to-use plastic testing device. The test was performed in accordance with the directions provided in the accompanying manual. The test result was negative when no colour change was observed after 5 minutes, positive when the colour changed to dark purple and equivocal when the colour turned green. Patients with at least one negative test were regarded as non-adherent.

Urine colour test

Prior to each INH urine test, urine colour was checked for the presence of rifampicin. Orange urine was scored as positive and yellow urine as negative. Patients with at least one negative test were categorized as non-adherent.

Morisky scale

The Morisky scale is a self-report adherence measure with four questions about common barriers to adherence.23 We classified as non-adherent all patients who answered “yes” to at least one of the four questions in at least one of the three repeated tests.

Brief Medication Questionnaire

The BMQ consists of three sections (“screens”) with questions about adherence behaviour, the experienced effects of treatment and other factors that could affect adherence. The screens were scored as described elsewhere.24 Patients with a total score of 1 or more in at least one of the three repeated tests were classified as non-adherent.

AIDS Clinical Trials Group adherence questionnaire

The adapted ACTG adherence questionnaire was developed for patients infected with the human immunodeficiency virus (HIV) who participate in clinical trials and is available at www.ghdonline.org/uploads/ACTG_Adherence_Baseline_Questionnaire.pdf (last accessed: 12 May 2011). Our adapted version consisted of three multiple choice items corresponding to sections B (social support), C (possible reasons for non-adherence) and D (adherence behaviour) of the original baseline questionnaire. We scored any answer other than “never” to the questions in sections C and D or less than “somewhat satisfied” to the questions in section B as positive. A positive score was regarded as indicative of non-adherence.

Refill visits and pill counts

The patients’ clinic attendance for medication refills was registered and remaining tablets were counted at every refill visit. Patients who delayed at least once for a medication refill visit and those who had an incorrect number of tablets remaining at least once were classified as non-adherent.

Data analysis

MEMS data were analysed by using Powerview software (AARDEX Ltd, Sion, Switzerland). Periods of “pocket dosing” (i.e. taking out medication for later use) that were identified by the MEMS use questionnaire were excluded from the analysis as non-monitored periods. Statistical analysis was performed in SPSS version 16.0 (SPSS Inc., Chicago, United States of America). Means are presented with standard deviation (SD) and medians with interquartile range (IQR). Means were compared by using the Student t-test. The sensitivity, specificity, positive and negative predictive values and accuracy of single and combined adherence measures were calculated by using MEMS as the gold standard. For combined measures, non-adherent patients were those who were classified as non-adherent by at least one of the single measures in the combination.
Ethical approval

The study was approved by the institutional review board of the Kilimanjaro Christian Medical Centre (Moshi, United Republic of Tanzania) and the National Institute for Medical Research (Dar es Salaam, United Republic of Tanzania).

Results

Patient characteristics and treatment outcomes

We enrolled 31 male and 19 female patients. Their characteristics are summarized in Table 1. Six of the 22 patients who were co-infected with HIV used antiretroviral medication and 14 were on co-trimoxazole prophylaxis. Although all patients were on community-based DOT, seven had no formal treatment supporter.

Thirty-seven patients successfully completed treatment. Six patients died; all were HIV-positive. Three patients defaulted and four patients dropped out of the study (three were transferred to another region and one developed jaundice and his treatment had to be interrupted).

Treatment adherence according to MEMS

No MEMS data were available for three patients (one defaulter and two who died) because the medication bottle was not returned. For the other 47 patients, a total of 6871 treatment days were monitored by MEMS. On 194 monitored days the MEMS bottle was not opened; the median per patient was 2 days (IQR: 0–5). The mean adherence rate was 96.3% (SD: 7.7) and did not differ significantly between patients with and without a treatment supporter: 96.2% (SD: 8.2) and 97.1% (SD: 3.1), respectively ($P = 0.79$).

Adherence was less than 100% in 70% of all patients; less than 95% in 21% of them, and less than 80% in 2% (Table 2). Among the patients who completed the six-month treatment course, adherence was less than 100% in 73%, less than 95% in 19% and less than 80% in none, respectively.

Monthly adherence rates were fairly constant. In the group of patients who completed treatment, the median monthly adherence rate was 100% and the mean monthly adherence rate varied between 95.4% (SD: 7.3) in month 6 and 98.5% (SD: 2.7) in month 3.

Validation of adherence measures

For the validation of the alternative adherence measures only patients who completed the six-month treatment course ($n = 37$) were included. As shown in Fig. 1, the proportions of non-adherent patients identified by the different measures varied widely. Table 3 shows the sensitivity, specificity, positive and negative predictive value and accuracy of the adherence measures in terms of their ability to differentiate between adherent and non-adherent patients. The ACTG adherence questionnaire and urine colour test had the highest sensitivities but lowest specificities. The Morisky scale and refill visits had the highest specificities but lowest sensitivities. The sensitivities of most measures improved when the cut-off value to differentiate be-

Jossy van den Boogaard et al. Monitoring treatment adherence electronically in tuberculosis patients

Table 2. Median monitored treatment days and adherence rates, and proportions of patients who were less than 100%, 95% and 80% adherent, as assessed by the Medication Event Monitoring System (MEMS), United Republic of Tanzania, 2010

<table>
<thead>
<tr>
<th>Patients</th>
<th>Monitored days</th>
<th>Adherence rate (%)</th>
<th>&lt;100% adherent</th>
<th>&lt;95% adherent</th>
<th>&lt;80% adherent</th>
</tr>
</thead>
<tbody>
<tr>
<td>All (47)</td>
<td>168 (138–172)</td>
<td>98.4 (95.7–100)</td>
<td>33 (70)</td>
<td>10 (21)</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Completed treatment (37)</td>
<td>169 (168–180.5)</td>
<td>98.4 (95.7–100)</td>
<td>27 (73)</td>
<td>7 (19)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Defaulters (2)</td>
<td>40.0/113c</td>
<td>50.0/100d</td>
<td>1 (50)</td>
<td>1 (50)</td>
<td>1 (50)</td>
</tr>
<tr>
<td>Deaths (4)</td>
<td>63 (29.5–104)</td>
<td>98.4 (95.6–99.6)</td>
<td>3 (75)</td>
<td>1 (25)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Study drop outs (4)</td>
<td>33 (21–73)</td>
<td>98.3 (88.4–100)</td>
<td>2 (50)</td>
<td>1 (25)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

IQR, interquartile range.

a Only patients for whom MEMS data were available are included.

b All values given are medians and IQRs except for the values of the two defaulters.

c Number of monitored days for defaulter 1 and defaulter 2, respectively.

d Adherence rates of defaulter 1 and defaulter 2, respectively.

Patients’ experience with MEMS use

The questionnaire about the use of MEMS, which was filled out by the 37 patients who completed treatment, revealed that only one patient had correctly understood the purpose of MEMS despite verbal and written information at the onset of the study. Twenty-five patients (68%) stated that the white, bulky appearance of the MEMS bottle reminded them to take the medication. However, the other patients said that the use of MEMS had not influenced their adherence behaviour. Mean adherence rates did not differ between these two groups: 97.5% (SD: 3.0) and 97.3% (SD: 3.2), respectively ($P = 0.86$).

Eight patients occasionally opened the MEMS bottle to take out medication for later use (resulting in a total of 42 non-monitored treatment days). This usually occurred when patients did not want to take the bottle along on travel occasions.

Discussion

This is the first study in which MEMS was used to assess treatment adherence rates in patients on community-based DOT over the full six-month tuberculosis treatment course. We observed high adherence rates in our pilot study of 50 Tanzanian patients. Almost 80% of the patients were more than 95% adherent and only one patient was less than 80% adherent. These findings do not confirm the concern that patients on community-based DOT are prone to become non-adherent, even though the study did reveal that some patients (i.e. those without a formal treatment supporter) turn community-based DOT into unsupervised treatment.

The participants’ demographic characteristics, such as the ratio of males to females and their treatment outcomes, were comparable to those of the general tuberculosis patient population in the Kilimanjaro region. This suggests that we studied a regionally representative patient sample. However, the adherence rates of our patients could have been biased by their participation in the study. Although we tried to deviate as little as possible from routine practice, the repeated adherence questionnaires and urine tests certainly made participants aware of our interest in their adherence behaviour. Two thirds of the patients felt that their adherence behaviour had been influenced by the use of MEMS, but their average adherence rate did not differ from those observed among patients who stated that MEMS had not influenced their behaviour. Findings from other studies suggest that when MEMS is used over long periods, its "interventional
The main objective of our study was to use MEMS as a reference standard to calculate the validity of several adherence measures whose use is feasible in patients on community-based DOT in resource-limited settings. The high adherence rates in the study population forced us to apply high adherence rate cut-off values to calculate the validity and reliability of the adherence measures. This resulted in wide gaps between the sensitivities and specificities of the measures. Combinations of measures were found to be more accurate than single measures in identifying as many true non-adherent patients as possible (reflected in high sensitivities and negative predictive values). The sensitivity and negative predictive value of the routinely used combination of pill counts and clinic attendance for medication refills improved substantially by adding a simple and cheap measure such as the ACTG adherence questionnaire, particularly at an adherence rate cut-off value of 95%.

The rifampicin urine colour test classified more patients as non-adherent than the INH urine test. Since the orange urine colouration caused by rifampicin is of short duration and may be absent altogether, it is likely that the urine colour test misclassified some patients with yellow urine as non-adherent. Such misclassifications are difficult to confirm in a study population with high adherence rates.

The adapted ACTG adherence questionnaire yielded more favourable responses than the other self-report measures. Differences in wording in the questionnaires may account for this. While patients had to answer either “yes” or “no” to the questions in the Morisky scale, they could answer “often”, “sometimes”, “rarely”, or “never” to comparable questions in the ACTG adherence questionnaire. This wider range of choice options may have evoked more honest replies. The ACTG adherence questionnaire (and to a lesser extent the BMQ) has the added advantage of disclosing factors that cause non-adherence in the individual patient. These factors could be used to design tailored interventions for promoting adherence among non-adherent patients on community-based DOT. We therefore suggest using the triple combination consisting of the ACTG adherence questionnaire.

### Table 3. Sensitivity, specificity, positive and negative predictive values, and accuracy of individual treatment adherence measures, alone and in combination, in a study of adherence to tuberculosis treatment, United Republic of Tanzania, 2010

<table>
<thead>
<tr>
<th>Adherence measure</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEMS cut-off</td>
<td>MEMS cut-off</td>
<td>MEMS cut-off</td>
<td>MEMS cut-off</td>
<td>MEMS cut-off</td>
</tr>
<tr>
<td></td>
<td>&lt;100%</td>
<td>&lt;95%</td>
<td>&lt;100%</td>
<td>&lt;95%</td>
<td>&lt;100%</td>
</tr>
<tr>
<td>INH urine test</td>
<td>33</td>
<td>43</td>
<td>40</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Urine colour test</td>
<td>74</td>
<td>86</td>
<td>20</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>ACTG questionnaire</td>
<td>54</td>
<td>57</td>
<td>70</td>
<td>90</td>
<td>70</td>
</tr>
<tr>
<td>BMQ</td>
<td>63</td>
<td>60</td>
<td>45</td>
<td>65</td>
<td>45</td>
</tr>
<tr>
<td>Pill counts</td>
<td>41</td>
<td>29</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Refill visits</td>
<td>22</td>
<td>14</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Refill visits + pill counts</td>
<td>33</td>
<td>29</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Refill visits + pill counts + ACTG questionnaire</td>
<td>41</td>
<td>29</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Refill visits + pill counts + urine colour test</td>
<td>74</td>
<td>86</td>
<td>20</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Refill visits + pill counts + BMQ</td>
<td>63</td>
<td>60</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Refill visits + pill counts + INH urine test</td>
<td>74</td>
<td>86</td>
<td>20</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Refill visits + pill counts + Morisky scale</td>
<td>63</td>
<td>60</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
</tbody>
</table>

ACTG, AIDS Clinical Trials Group; BMQ, Brief Medication Questionnaire; INH, isoniazid; MEMS, Medication Event Monitoring System; NPV, negative predictive value; PPV, positive predictive value.

- **Sensitivity**: the proportion of non-adherent individuals correctly identified as non-adherent by the measure.
- **Specificity**: the proportion of adherent individuals correctly identified as adherent by the measure.
- **Positive predictive value**: the proportion of non-adherent individuals according to the measure who were non-adherent according to MEMS.
- **Negative predictive value**: the proportion of adherent individuals according to the measure who were adherent according to MEMS.
Monitoring treatment adherence electronically in tuberculosis patients

Jossy van den Boogaard et al.

Abstract

Suivi électronique de l’adhésion au traitement et validation de mesures d’adhésion alternatives des patients tuberculeux: une étude pilote

Objectif Évaluer l’adhésion au traitement directement observé en milieu communautaire des patients tuberculeux tanzaniens, à l’aide du système de suivi des événements de médication (MEMS, Medication Event Monitoring System) et valider les mesures d’adhésion alternatives dans les configurations de ressources limitées utilisant le MEMS comme critère de référence.

Méthodes Il s’agissait d’une étude pilote longitudinale sur 50 patients recrutés consécutivement dans un hôpital rural, un hôpital urbain et deux centres de soins urbains. L’adhésion au traitement a été contrôlée par le système de suivi des événements de médication (MEMS).

Résultats La moyenne d’adhésion observée était de 96.3% pour les patients recrutés dans les hôpitaux, et de 78.8% pour ceux recrutés dans les centres de soins urbains. Les mesures d’adhésion alternatives étaient validées par des coefficients de corrélation de 0,8 à 0,9 entre les deux méthodes.

Conclusion L’usage du système de suivi des événements de médication (MEMS) et des mesures d’adhésion alternatives est un moyen valable de contrôler l’adhésion au traitement dans les hôpitaux ruraux et urbains.

Keywords Évaluation de l’adhésion au traitement, suivi des événements de médication, mesures d’adhésion alternatives.
MEMS and the validity of the measures of adherence consequent have been evaluated: test urine for detecting the presence of isoniazid, test of coloration of the urines, a questionnaire of Morisky, the medication, questionnaire of adherence adapted of the Group of trials of the SIDA (ACTG, AIDS Clinical Trials Group), counts of pills and visits of reassessment in medicines.

**Results** The rate of adherence in the population of the study, it was attaining 96.3% (deviation standard, DS: 7.7). The adherence was inferior to 100% to 70% of the patients, inferior to 95% to 21% of patients and inferior to 80% to 2% of patients. The questionnaire of adherence of the ACTG and the test of coloration of urines presented the sensitivities most elevated, but the specificities the most low. The study of Morisky and the visits of reassessment presented the specificities the most elevated, but the sensitivities the most low.

The patients subsequent to a treatment directly observed in the community have shown an adherence better. The combination of the counts of pills, the visits of reassessment and of the questionnaire of adherence of the ACTG could be used for controlling the adherence in the cases where the MEMS was not available. The results in terms of adherence and of validity of the measures of adherence simples were confirmed to several populations and large, with an reliability the most important of the rates of adherence.

**Conclusions** The adherence was 70% of patients, inferior to 95% in 21% of patients. The adherence was inferior to 100%, y 21% – inferior 95% and y 2% inferior 80%. When the Morisky's test and the visits of reassessment, used for filling the stocks of medicines had shown a correctness of adherence.

The adherence was made high, but the specificities low. The Morisky's test and the visits of reassessment had shown a correctness of adherence.

**Conclusion** The adherence was 70% of patients, inferior to 95% in 21% of patients. The adherence was inferior to 100%, y 21% – inferior 95% and y 2% inferior 80%.
en este estudio. La combinación del recuento de medicación, las visitas de aprovisionamiento de medicamentos y el cuestionario de cumplimiento ACTG podría emplearse para controlar el cumplimiento en entornos en los que el uso del sistema MEMS no resulte viable económicamente. Los resultados en cuanto al cumplimiento y a la validez de las medidas sencillas de cumplimiento podrían confirmarse en poblaciones más amplias con una mayor variabilidad de tasas de cumplimiento.

References


Research