Use of Dried Spots of Whole Blood, Plasma, and Mother’s Milk Collected on Filter Paper for Measurement of Human Immunodeficiency Virus Type 1 Burden

Workenesh Ayele,1 Rob Schuurman,3 Tsehaynesh Messele,1 Wendelien Dorigo-Zetsma,4 Yohannes Mengistu,5 Jaap Goudsmit,6 William A. Paxton,7 Michel P. de Baar,2 and Georgios Pollakis7*  

Ethio-Netherlands AIDS Research Project, Addis Ababa, Ethiopia1; Primagen, Amsterdam, The Netherlands2; Department of Virology, University Medical Center Utrecht, Utrecht, The Netherlands3; Regional Microbiological and Serological Laboratory, Hospital Hilversum, Hilversum, The Netherlands4; Department of Microbiology, Immunology and Parasitology, Faculty of Medicine, Addis Ababa University, Ethiopia5; Crucell Holland B.V., Leiden, The Netherlands6; and Department of Human Retrovirology, University of Amsterdam, Amsterdam, The Netherlands7

Received 15 September 2006/Returned for modification 4 December 2006/accepted 17 December 2006

We studied the use of dried spots of bodily fluids (plasma, whole blood, and mother’s milk) on filter paper as a means of sample collection and storage for human immunodeficiency virus type 1 (HIV-1) viral load testing under stringent field conditions. Plasma placed directly in lysis buffer, which is customarily used for viral load assays, was used for comparison in all our experiments. Utilizing reconstruction experiments, we demonstrate no statistical differences between viral loads determined for plasma and mother’s milk spotted on filter paper and those for the same fluids placed directly in lysis buffer. We found that the addition of whole blood directly to lysis buffer was unreliable and could not be considered a feasible option. However, viral load measurements for whole blood spotted onto filter paper correlated with plasma viral load values for both filter spots and lysis buffer (Pearson correlation coefficients, 0.7706 and 0.8155, respectively). In conclusion, dried spots of plasma, whole blood, or mother’s milk provide a feasible means for the collection, storage, and shipment of samples for subsequent viral load measurement and monitoring. Virus material spotted and dried on filter paper is a good inexpensive alternative for collecting patient material to monitor the HIV-1 viral load. Measuring the HIV-1 burden from whole blood dried on filter paper provides a suitable alternative for low-technology settings with limited access to refrigeration, as can be found in sub-Saharan Africa.

For patients infected with human immunodeficiency virus (HIV) in resource-limited settings, in recent years there has been increased access to antiretroviral therapy (7), which has led to a growing need to have monitoring systems in place that are capable of assessing the effects of these treatments. Monitoring therapy in the context of many developing nations poses unique challenges. More than 90% of new HIV infections occur in developing countries where there is limited access to equipment for processing specimens, and these countries often also have inadequate storage facilities for preserving sample integrity until testing. In order to overcome the logistical obstacles, innovative approaches to simplifying methods of sample collection from far-to-reach areas have been applied with good results. Spotting and drying blood samples on filter paper for clinical testing has proven to be a highly effective method for sample collection and storage (5, 11). Various types of paper were used in screening for various metabolic disorders in neonates (4, 38). Recently, this method has been applied more widely to the diagnosis of other infectious diseases as well, since this approach is feasible for the collection of large numbers of field specimens (19, 22, 26, 31, 36, 37).

To provide alternative ways to obtain viral load measurements, we developed and evaluated the use of filter papers as a collection and storage medium for HIV-1-infected blood, plasma, and breast milk samples. Analyses were performed in combination with the Primagen Retina Rainbow assay for viral load measurements, which is able to detect all known subtypes and circulating recombinant forms (CRFs) of HIV-1. Dried plasma spot technology is the least expensive way of shipping samples that have been spotted on filter paper and dried. Once samples are dried on filter paper, they remain stable for HIV-1 RNA detection for long periods of time (9, 11), and virus that is spotted is no longer infectious (http://www.cdc.gov/od/ohs/biosafety/driblood.htm), and therefore this approach also provides an inexpensive way to store samples for future analysis. In addition to dried plasma and mother’s milk spots, we tested dried whole-blood spots, as this would be the simplest formulation for sample collection. In addition, we compared the Rainbow assay (13) to the Roche Amplicor 1.5 HIV-1 monitor assay, the most widely used technology in the field.

MATERIALS AND METHODS

Reconstruction experiments for viral load measurements. We evaluated filter paper as a carrier and storage medium for HIV nucleic acids under reconstructed experimental conditions where virus was spiked into a body fluid. The human plasma used was collected as a by-product of the lymphocyte purification protocol, and human milk (surplus) was donated by a breast-feeding mother.

We used a panel of virus isolates, comprising all subtypes and circulating recombinant forms 1 and 2 (CRF01/CRF02). The isolates were quantified by
using several methods, including electron microscopy (17). Each virus was di-
ulated in the body fluid in use and at the desired concentrations, ranging from 100
to 1,000,000 virus particles per milliliter. Subsequently 200 µl of the fluid spiked
with the virus was dissolved in lysis buffer (L6) as required for RNA isolation by
the method of Boom and colleagues (8) or laid on Schleicher & Schuell 903 filter
paper (Keene, NH) in four spots of 50 µl each. All samples spotted on paper
were air dried for 30 min and then stored, sealed in a bag with desiccant, for 24 h
to several weeks at room temperature.

Subjects and samples. Validation of the method using air-dried filter paper for
clinical samples was performed for two sets of blood-derived material collected
from HIV-1-infected individuals.

A set of 103 plasma samples was collected between January 2000 and Decem-
ber 2002 from 103 HIV-1-infected patients visiting the outpatient clinic of the
University Medical Center of Utrecht University in The Netherlands. Immedi-
ately upon arrival, Portions of samples were analyzed for HIV-1 viral RNA levels
by using the Amplicor 1.5 assay, whereas the remainders of the samples were
stored at −80°C until further use. These samples encompassed a range of viral
loads from >6 log_{10} copies RNA per ml to values below the detection level of the
Amplicor assay, which means <50 copies RNA per ml. Of the 103 plasma
samples, 19 were proven to be of a non-B subtype.

A set of 35 samples collected in Ethiopia in 2003 were from HIV-1-seropos-
itive individuals enrolled in an Ethiio-Netherlands AIDS Research Project cohort
of factory workers. The cohort was formed to study the natural history of HIV-1
infection in Ethiopia and has been described elsewhere (34, 35). Blood was
collected using EDTA anticoagulant as required for routine viral load determi-
nation using the NucliSSENS HIV-1 QT assay (bioMerieux, Boxtel, The Nether-
lands) with the Virusell assay. Three healthy seronegative cohort participants
were included as controls. For the purpose of the study, each of these samples was
prepared four different ways, and all four preparations were compared in our
analysis. Whole blood or plasma (200 µl) was aliquoted in lysis buffer and stored
immediately at −80°C until processing. Additionally, same-volume amounts of
whole blood and plasma were spotted on filter paper in four spots of 50 µl each.

Viral load determination. Viral RNA from all samples was assayed by the
Primagene Retina Rainbow assay, performed according to the instructions of the
manufacturer. In short, 5 µl of purified nucleic acid from a total elution volume
of 50 µl was assayed by mixing it with the amplification reagents. After the
addition of the enzymes, the samples were placed in a fluorimeter with a ther-
mostat for 90 min. After the run, the results were analyzed and reported as the
number of copies per milliliter or “<500 copies per ml” if the sample was positive
but not quantifiable or “not detectable” if no signal was detected.

The method for isolating virus RNA from HIV-1-containing fluids that were
dissolved in lysis buffer was previously described (8). For the filter paper spots,
there was an additional elution process after punching of the plasma spots of
the paper. All four spots were incubated for at least 2 h or overnight at room
temperature in 3 ml lysis buffer following the removal of the papers from the lysis
buffer or laid as spots on blotting paper. Figure 1 shows the correlation of the viral RNA measurements generated by the

RESULTS

Reconstruction experiments. By adding cultured virus particles to uninfected human plasma or mother’s milk, we recon-
structed samples with known RNA copy contents (17) prior to quantification by the Rainbow assay. We used viral isolates
that had previously been quantified by electron microscopy to reconstruct samples with virus concentrations spanning a range of
2 to 6 log_{10}. The virus-spiked samples were subsequently processed in two different ways, either directly dissolved in lysis
buffer or laid as spots on blotting paper. Figure 1 shows the correlation of the viral RNA measurements generated by the
two formulations (virus in plasma or in milk subsequently
dissolved in lysis buffer or spot dried on paper). Regardless of
whether human plasma or mother’s milk was used as a carrier prior to the viral isolation, there was a high correlation be-
tween the two formulations: the Pearson correlation coefficients were 0.91 for the plasma set processed directly in lysis
buffer or via dried spot and 0.93 for the mother’s milk set (P
was <0.001 for both). A good linear correlation was found
between the values we generated with the Rainbow Retina
assay and the theoretical values according to the electron mi-
croscopy quantification (Pearson correlation coefficient, 0.82;
P < 0.001 [data not shown]). Furthermore, when we compared the
results from the paper blot formulations for plasma and
milk (Pearson correlation coefficient, 0.99; P = 0.001) a good
linearity across the 5-log range (r^2 = 0.98) was observed (data
not shown).

These results provide evidence that the isolation and quant-
ification of viral RNA from samples collected on blotting
paper is a viable alternative to the traditional freezing method
for the transportation of clinical samples. This is an important
incentive for limited-resource settings, especially under the
consideration that monitoring will be a key factor in curtailing
the HIV-1 pandemic.

Evaluation of the viral RNA measurements with subtype B
viruses. A total of 84 patient samples from The Netherlands,
all infected with a subtype B virus, were selected for the com-
parison of the two formulations, plasma in lysis buffer and
plasma on paper. These samples had previously been analyzed
with the Amplicor 1.5 assay, and the viral load values ranged
from undetectable to log_{10} 6.5. The RNA copy number values
generated by the Retina Rainbow assay for both plasma in lysis
buffer and plasma on paper were compared (Fig. 2A). The
correlation was high, with a Pearson correlation coefficient of
0.96 (P < 0.001).
Since the viral load values measured by the Roche Amplicor 1.5 HIV RNA assay were available to us, we compared them with the results we generated with the Retina Rainbow assay (Fig. 2B). The Amplicor assay has a sensitivity of approximately 50 copies per ml, and the Retina Rainbow assay in its standard format has a sensitivity of 500 copies per ml. This indicates that values of between 50 and 500 copies per ml are unlikely to be detected with the Retina Rainbow assay. The samples that were part of the comparison studies were selected based on the Amplicor results. With this method, there was a one-sided bias in the lower range in favor of the Amplicor assay since all samples were positive with the Amplicor assay and likely negative with the Rainbow assay.

Evaluation of the viral RNA measurements with non-subtype B viruses. Since the vast majority of HIV-1 isolates worldwide encompasses subtypes other than B (non-B), with subtype C being the most prevalent, we wanted to verify that non-B HIV-1 isolates could be detected equally as well as subtype B plasma isolates spotted on paper. For this purpose, we analyzed a set of 19 plasma samples from The Netherlands. The samples were collected from individuals infected with non-B HIV-1 viruses (CRF01 AE, CRF AG, D, and C, including one CRF06-cpx and one K), together with a set of 19 plasma samples collected from HIV-1 subtype C-infected individuals in Ethiopia. The subtype C isolates were detected with a correlation similar to that of the subtype B isolates (Fig. 3).

These samples were analyzed by the Rainbow assay, dissolved directly in lysis buffer, or laid as four 50-μl spots on blotting paper. The correlation between the two formulations was similar to that for the subtype B isolates, with a Pearson correlation coefficient of 0.9164 and a linearity $r^2$ value of 0.8398.

Viral load measurements for whole-blood dried spots. The purpose of this study was to show that there are simpler, low-cost ways of monitoring HIV-1 viral load measurements. We therefore wanted to study whether whole blood collected from a finger prick, for example, would be feasible for viral load measurements since it is less expensive and laborious than separating plasma from whole-blood specimens. When viral RNA was isolated from whole blood dissolved directly in lysis buffer, the viral load values generated by the Rainbow assay were not reproducible and correlated poorly with values obtained from the plasma from the same donor in lysis buffer. Also, the whole-blood values were systematically lower than those of the plasma samples (data not shown). This indicates that there are factors in whole blood that inhibit efficient isolation and/or amplification of the viral genetic material. Collecting whole blood in lysis buffer would therefore not be a valid method for sample collection for subsequent viral load measurement. Nevertheless, we found that measurements for whole blood after it had been spotted and dried on filter paper correlated well with those for plasma in lysis buffer or plasma spotted on paper (Fig. 4A). The Pearson correlation coeffi-
cients were 0.7706 for plasma in lysis buffer and 0.8155 for plasma spotted on paper. Despite the fact that we analyzed a set of only 17 samples, we found no significant difference between the values for the samples and the values generated from plasma placed directly in lysis buffer (Fig. 4B). The values generated for the whole-blood spots tended to be slightly lower than those for the plasma samples, but we did not take into account the relative volume differences due to the high red blood cell content of whole blood, which adjustments could be made for.

**DISCUSSION**

The increased access to life-saving antiretroviral drugs has raised hope for many AIDS patients in resource-limited countries but also raises challenges for appropriate monitoring. The determination of viral endpoints remains the gold standard by which current clinical trials assess HIV treatment efficacy (21, 28). Besides, viral load measurement has an established value in predicting clinical progression to disease (14, 24, 25, 33), in monitoring response to antiretroviral therapy (20, 33), and in assessing the risk of vertical transmission by HIV-seropositive mothers to newborns (16, 27). However, for many areas in the developing world, the prohibitive costs of carrying out viral RNA measurements is limiting and has mandated the search for suitable alternatives validated against this standard (18, 23). The costs associated with carrying out viral viral load testing in developing nations can be partially decreased by the development of suitable technologies allowing simpler methods of sample collection and preservation. Samples collected in this way may be subsequently transported to centralized testing facilities without the risk of specimen deterioration and without the need for expensive shipping facilities, including those necessary for dry-ice shipping.

The detection of HIV-1 DNA (11, 30) or RNA (3, 10, 36) by using dried blood specimens collected on filter paper has previously been reported. Apart from its use for viral load testing, the dried blood spot (DBS)/dried plasma spot technique of sample collection has been utilized for other purposes, including, due to the small volumes required, conducting studies on perinatal HIV transmission (6, 16). In addition, molecular epidemiology studies for genotyping HIV-1 have also exploited the technique (12, 32).

Recently the DBS technology was extended further to provide a simple method for CD4+ cell enumeration feasible to undertake in the field (29). Using a combined viral load and CD4 measurement for one sample of dried whole blood, such as that from a heel or finger prick, would be optimal for monitoring patients on antiretroviral programs in resource-limited settings like Ethiopia. The current investigation suggests that whole blood spotted on filter paper could be a way of monitoring high viral loads or dramatic therapy failures. Plasma spotted onto filter paper provided a better estimation of HIV-1 viral load in a patient than did plasma in lysis buffer as a reference. Logistically this presents the added step of requiring blood collection equipment for the separation of plasma from whole blood, which may not always be readily available in remote areas. If the feasibility of using dried whole-blood spots for CD4 cell enumeration is demonstrated satisfactorily in Ethiopia, whole-blood spotting onto filter paper immediately after collection could be followed by the spotting of plasma for the viral load testing aspect.

Previously it was shown that the porphyrin moiety of heme from contaminating erythrocytes inhibits nucleic acid amplification by PCR (1), but the blotting of blood on paper could lead to irreversible absorption of inhibiting factors. In our study, while whole blood placed directly in lysis buffer remains unreliable, with blood spotted on paper, a substantial amount of inhibiting factors seemed to be retained on the filter paper during the process of RNA extraction, providing a good readout.

The dried blood and plasma spots used in this study were maintained at room temperature (22 to 24°C) at the site of sample processing, with no perceptible loss of viral RNA com-

![FIG. 4. Assessment of whole blood collected as dried spots on filter paper for the monitoring of HIV-1 viral burden. (A) The log_{10} RNA values derived from 200 μl blood spotted on filter paper were plotted against the log_{10} RNA values derived from 200 μl plasma dissolved in lysis buffer (solid line/closed circles) or against the log_{10} RNA values derived from 200 μl plasma spotted on filter paper (broken line/open circles). (B) A pairwise comparison of the log_{10} RNA values from whole blood spotted on paper to the log_{10} RNA values from plasma dissolved in lysis buffer, which is the standard formulation.]
pared to that with the standard approach of sample collection, processing of plasma, and storing at −80°C in lysis buffer until analysis. The data were in agreement with findings by other investigators who report remarkable stability of RNA under extreme climate or prolonged storage conditions (9, 15). We found that the correlation was highest with the plasma spot/plasma in lysis buffer comparison, which was also consistent with a high correlation reported by other investigators (10).

We used the long-terminal repeat (LTR)-based Retina Rainbow viral load assay for our study since this assay was previously shown to consistently detect all subtypes of HIV-1, even those that were underdetected using other commercially available tests (13). In addition, it has a format adaptable for use with either dried blood or dried plasma specimens. Parallel testing of plasma samples in our study by using the more established Amplicor assay, together with the Retina Rainbow test, showed that the results of the two assays correlated well. In addition, the comparability of the Retina Rainbow assay with the NucliSENS assay was similarly good (data not shown), with both being reported to efficiently detect HIV-1 subtype C (2, 13), the dominant subtype both worldwide and in our Ethiopian cohort.

Providing an easy way of collecting, storing, and shipping samples can aid in the monitoring of circulating strains of virus in different parts of the globe, usefully contributing to the monitoring of vaccine efforts and therapy distribution to curtail the pandemic. From the present study, it can be concluded that this technology may be used meaningfully in resource-limited settings for the collection of specimens from populations not readily served by laboratories. This technology is feasible to carry out under field conditions without access to refrigeration or electrical power supply, although the results presented here suggest that HIV viral load testing from samples of whole blood as dried spots, in combination with the Retina Rainbow assay, requires somewhat further optimization. DBS/dried plasma spot technology offers the advantages of a stable environment for the analysis and ease of sample collection and shipment with minimal biohazard risks, thereby providing a highly suitable and affordable alternative to the common practice and one that could be exploited for multiple purposes.

ACKNOWLEDGMENTS

This study is part of the Ethio-Netherlands AIDS Research Project (ENARP), a collaborative effort of the Ethiopian Health and Nutrition Research Institute (EHNRI) in Addis Ababa, Ethiopia, the Amsterdam Municipal Health Service (GG/GD), the Department of Human Retrovirology of the Academic Medical Center (University of Amsterdam), and the Central Laboratory of The Netherlands Red Cross Blood Transfusion Service (CLB).

ENARP is financially supported by The Netherlands Ministry of Foreign Affairs and the Ethiopian Ministry of Health (MOH) as a bilateral project. This work was partly funded through a grant from the Elizabeth Glaser Pediatric AIDS Foundation (27-PG-51269).

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