

# Rapid detection of human immunodeficiency virus type 1 group M by a reverse transcription-loop-mediated isothermal amplification assay

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1 **Rapid Detection of Human Immunodeficiency Virus Type 1 group M by a Reverse**  
2 **Transcription-Loop-Mediated Isothermal Amplification Assay**

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21

## 1 Abstract

2 A rapid one-step reverse transcription-loop-mediated isothermal amplification (RT-  
3 LAMP) assay targeting the *pol*-integrase gene was developed to detect human  
4 immunodeficiency virus type 1 (HIV-1) group M. This HIV-1 RT-LAMP assay is  
5 simple and rapid, and amplification can be completed within 35 min under isothermal  
6 conditions at 60°C. The 100% detection limit of HIV-1 RT-LAMP was determined  
7 using a standard strain (WHO HIV-1 [97/656]) in octuplicate and found to be 120  
8 copies/ml. The RT-LAMP assay was evaluated for use in clinical diagnosis using  
9 plasma samples collected from 57 HIV-1-infected and 40 uninfected individuals in  
10 Cameroon, where highly divergent HIV-1 strains are prevalent. Of the 57 samples from  
11 infected individuals, 56 harbored group-M HIV-1 strains, such as subtypes A, B, G, F2,  
12 and circulating recombinant forms (CRF)<sub>01</sub>, <sub>02</sub>, <sub>09</sub>, <sub>11</sub>, <sub>13</sub>; all were RT-LAMP  
13 positive. One sample harboring group-O HIV-1 and the 40 HIV-1-uninfected samples  
14 were RT-LAMP negative. These findings indicate that HIV-1 RT-LAMP can detect  
15 HIV-1 group-M RNA from plasma samples rapidly and with high sensitivity and  
16 specificity. These data also suggest that this RT-LAMP assay can be useful for  
17 confirming HIV diagnosis, particularly in resource-limited settings.

18

19 Keywords: LAMP, HIV-1 group M, Confirmatory test

20

## 1 **1. Introduction**

2       The number of people living with human immunodeficiency virus (HIV) infection  
3 was estimated at 33 million as of December 2007, and over 2.7 million people acquired  
4 new HIV infections in 2007 (UNAIDS, 2008). HIV testing and counseling have been  
5 recognized as entry points for prevention, care, treatment, and support (World Health  
6 Organization, 2004). Recently, rapid serological HIV tests have been introduced to  
7 facilitate radical scaling up of HIV testing and counseling services in many settings,  
8 such as in diagnosing and treating sexually transmitted infections, in services providing  
9 and linked to the prevention of mother-to-child transmission, and in general medical  
10 settings (World Health Organization, 2004). It has been shown that sequential  
11 combinations of two or three antibody (Ab) tests (ELISA and/or rapid tests) are reliable  
12 for confirming HIV-positivity (World Health Organization, 2004; Aghokeng et al.,  
13 2004; Carvalho et al., 1996; Meda et al, 1999). However, considering that the fourth  
14 generation HIV ELISA test, which can detect both HIV P24 antigen and HIV Ab in the  
15 same sample simultaneously, has been introduced to detect early-stage HIV infection  
16 (Meda et al., 1999) and that a combined antigen-Ab rapid test for diagnosing HIV will  
17 be introduced soon (Keren et al, 2008), a method for rapidly detecting HIV-1 RNA  
18 and/or proviral DNA to confirm HIV diagnosis in these settings would be a valuable  
19 diagnostic aid.

20       HIV-1 is classified into three groups: M, N, and O. Group M, which accounts for  
21 the HIV pandemic, is further classified into nine major clades (A-D, F-H, J, and K) and

1 42 circulating recombinant forms (CRFs; Heeney et al., 2006; Powell et al., 2007; HIV  
2 sequence Compendium 2008). The diverse nature of HIV causes difficulties in  
3 nucleotide-based diagnoses of HIV infection. In addition, low HIV DNA burden and  
4 low concentrations of HIV RNA in plasma often result in failure to detect HIV RNA or  
5 DNA in clinical specimens (Zazzi et al., 1995). These two factors, high diversity and  
6 low plasma RNA/proviral DNA concentration, limit the ability to diagnose HIV  
7 infection reliably and efficiently.

8 The reverse transcription-loop-mediated isothermal amplification (RT-LAMP) assay  
9 developed by Notomi is a simple method for nucleotide-based diagnostics that exhibits  
10 high sensitivity and specificity (Notomi, et al., 2000). This method relies on auto-  
11 cycling strand displacement DNA synthesis by a DNA polymerase with high strand  
12 displacement activity and a set of two each of specially designed inner and outer primers.  
13 The entire RT-LAMP procedure can be completed in a single step at a constant  
14 temperature without a programmed thermal cycler. LAMP provides highly efficient  
15 DNA amplification, up to  $10^9$ - $10^{10}$  times in 15-60 min, and the concentration of the  
16 LAMP product is much higher than that generated by conventional polymerase chain  
17 reaction (PCR). Conventional PCR is relatively time consuming (3-4 h) and much more  
18 complicated than RT-LAMP, requiring several amplification steps and the use of a  
19 high-precision thermal cycler. The RT-LAMP assay has been validated and applied to  
20 the rapid detection of a number of RNA viruses, such as rubella virus (Mori et al., 2006),  
21 Japanese encephalitis virus (Toriniwa and Komiya, 2006), influenza virus (Ito et al.,

1 2006), mumps virus (Okafuji et al., 2005), West Nile virus (Parida et al., 2004), severe  
2 acute respiratory syndrome corona virus (Hong et al., 2004; Poon et al., 2005), measles  
3 virus (Fujino et al., 2005), dengue virus (Parida et al., 2005), respiratory syncytial virus  
4 (Ushio et al., 2005), and HIV-1 (Curtis et al., 2008).

5 In the present study, another RT-LAMP assay was developed for the rapid detection  
6 of HIV-1 RNA. Its intended application is on-site confirmation of HIV diagnosis.

7

## 8 **2. Materials and methods**

### 9 *2.1. Standard serum*

10 WHO standard 97/656 ( $10^5$  international units (IU) per vial, National Institute for  
11 Biological Standards and Control, Herts, UK) was used to determine the detection limit  
12 of the RT-LAMP assay (Davis et al., 2003; Holmes et al., 2001). The assay was carried  
13 out in octuplicate. The lowest concentration of genome copies with all octuplicate  
14 samples confirmed as positive was considered the detection limit.

15

### 16 *2.2. Human plasma samples*

17 Plasma samples were collected from 57 HIV-1-infected individuals in eastern  
18 Cameroon in 2001 (Ndembi et al., 2004) and 40 HIV-1-uninfected antenatal clinic  
19 attendees in western Cameroon in 2003. These samples were used to evaluate the  
20 sensitivity and specificity of HIV-1 RT-LAMP. In a previous study (Ndembi et al.,  
21 2004), phylogenetic analysis of genomic DNA samples from the 57 infected individuals

1 revealed the presence of highly divergent strains of HIV-1 circulating in eastern  
2 Cameroon (Table 1). The 40 samples from uninfected individuals collected in 2003  
3 were confirmed HIV-negative by HIV-Ab testing (AxSYM HIV1/2 and/or Determine  
4 HIV-1/2; Abbott Japan, Tokyo, Japan) and conventional PCR, as described previously  
5 (Ndembi et al., 2004).

6

### 7 *2.3. RNA preparation*

8 HIV RNA was extracted from plasma as follows: 200 µl of plasma was incubated  
9 with 400 µl of lysis buffer consisting of 10 mM Tris-HCl (pH 8.0), 68% (w/v)  
10 guanidine isothiocyanate, 3% (w/v) dithiothreitol, and 4 µl of co-precipitant (10 mg/ml  
11 amylopectin azure) at 25°C for 10 min. HIV RNA was precipitated by adding 600 µl of  
12 isopropanol and centrifuging at 20,000×g for 15 min. The RNA pellet was washed with  
13 70% ethanol and resuspended in 10 µl of RNase-free and DNase-free water.

14

### 15 *2.4. Primer design*

16 A set of primers that recognizes eight distinct target sites in the HIV-1 *pol*-integrase  
17 gene, a well-conserved region of HIV-1 genome, was designed based on the HIV-1  
18 genome sequence (GenBank accession number K02013) using a primer-designing  
19 software program for LAMP (Primer Explorer ver. 2.0; Net laboratory, Japan,  
20 <http://venus.netlaboratory.com>; Table 2). The set consisted of the six following primers:  
21 a forward inner primer (FIP), backward inner primer (BIP), two outer primers (F3 and

1 B3), and two loop primers (Loop F and Loop B). Two additional inner primers  
2 comprise the combination of two functionally different primer parts: FIP consists of F1c  
3 (complementary to F1) and F2 and BIP consists of B1c (complementary to B1) and B2.  
4 The sequences of the two loop primers are complementary to the primers located  
5 between regions corresponding to F1 and F2 primer sequences.

6

### 7 2.5. RT-LAMP assay

8 The RT-LAMP reaction was carried out in 25  $\mu$ l using a Loopamp DNA  
9 amplification kit (EIKEN Chemical Co., Ltd., Tochigi, Japan) containing FIP (40 pmol),  
10 BIP (40 pmol), F3 (5 pmol), B3 (5 pmol), Loop F (40 pmol), Loop B (40 pmol), *Bst*  
11 DNA polymerase (16 U), AMV reverse transcriptase (2 U), and 5  $\mu$ l of target RNA. The  
12 reaction mixture was incubated at 60°C for 60 min in a Loopamp real-time turbidimeter  
13 (LA-200; Teramecs, Kyoto, Japan; Fig. 1A). A turbidity value of more than 0.1 was  
14 considered positive. The amplified products of RT-LAMP were resolved by 2% agarose  
15 gel electrophoresis (Agarose S; Wako Pure Chemical Industries, Ltd, Osaka, Japan); the  
16 gel was stained with ethidium bromide and visualized using an ultraviolet (UV)  
17 transilluminator (Fig. 1B). The turbidity of the amplified products was also ascertained  
18 by naked eye. The amplified products were inspected further under UV irradiation with  
19 or without adding ethidium bromide, an intercalating dye, when RT-LAMP assay was  
20 carried out in the presence of Fluorescent Detection Reagent (EIKEN CHEMICAL Co.,  
21 LTD., Tokyo, Japan; Fig. 1C).



1

## 2 **3. Results**

### 3 *3.1. Development of the HIV-1 RT-LAMP assay*

4 Using the primer sets targeting the HIV-1 *pol*-integrase gene (Table 2), a one-step  
5 RT-LAMP assay for the rapid detection of HIV-1 RNA was standardized. The success  
6 of amplification was assessed using a real-time turbidimeter (LA-200; Fig. 1A).  
7 Threshold time (Tt), the time required for the turbidity value to exceed 0.1, is shown in  
8 Table 1. Amplification was also detected by the presence of a ladder-like pattern on a  
9 2% agarose gel. The ladder-like pattern results from a mixture of stem-loop DNAs of  
10 various stem lengths and cauliflower-like structures with multiple loops (formed by  
11 annealing between alternately inverted repeats of the target sequence in the same strand;  
12 Fig. 1B). Furthermore, amplification was detected by naked-eye inspection of turbidity;  
13 visual detection was enhanced further by the addition of Fluorescent Detection Reagent  
14 and/or the intercalating dye under UV irradiation (Fig. 1C).

15

### 16 *3.2. Sensitivity and specificity of the HIV-1 RT-LAMP assay*

17 The sensitivity of the RT-LAMP assay for detecting HIV-1 RNA was determined  
18 using RNA from WHO standard HIV-1 97/656 ( $10^5$  IU/vial) diluted to 6000, 600, 240,  
19 120, 90, and 60 copies/ml. One IU was reported to be equivalent to 0.62 genome copies  
20 (Davis et al., 2003). The assay was carried out in octuplicate using viral RNA extracted

1 from the equivalent of 100  $\mu$ l of diluted serum. The reproducible 100% detection limit  
2 of the RT-LAMP assay was 120 copies/ml.

3 Of the 57 HIV-1-positive samples, 54 were positive for RT-LAMP in 19.2 to 33.2  
4 min as assessed by turbidity using the LA-200 detection system (Table 1 and Fig. 1A).  
5 HIV-1 RT-LAMP products of the two samples that were not detected by the real-time  
6 turbidimeter (01CM2219 and 01CM2232) could be detected by agarose gel  
7 electrophoresis (Fig. 1B) and by the naked eye after adding the intercalating dye under  
8 UV irradiation in the presence of Fluorescent Detection Reagent (data not shown). The  
9 remaining sample (02CM319) containing HIV-1 group-O RNA was RT-LAMP  
10 negative (Table 1 and Fig. 1B). Thus, all 56 samples that harbored HIV-1 group-M  
11 were positive by HIV-1 RT-LAMP assay.

12 Plasma specimens obtained from 40 pregnant women without HIV infection were  
13 also subjected to RT-LAMP and all were confirmed negative.

14

#### 15 **4. Discussion**

16 An RT-LAMP assay was developed to detect HIV-1 RNA. This method was simple,  
17 rapid, and highly sensitive and specific for group-M HIV-1. Therefore, the HIV-1 RT-  
18 LAMP assay can be used as a rapid confirmatory test for HIV-1 group-M infection.

19 The HIV genome is usually detected by RT-PCR and PCR performed on plasma  
20 RNA and proviral DNA, respectively. These methods require at least 2-3 hours despite  
21 the implementation of real-time PCR. In this study, the HIV-1 RT-LAMP assay was

1 completed within 35 min, considerably faster than by RT-PCR or PCR. In addition,  
2 unlike RT-PCR and PCR, a simple apparatus such as a water bath can be used to  
3 maintain the constant incubation temperature at 60°C.

4 The RT-LAMP reaction yields a white precipitate of magnesium pyrophosphate in  
5 the reaction mixture, indicating a positive result. This white precipitate is easily  
6 detected by the naked eye (Fig. 1C); thus, the results of the assay can be assessed  
7 without a turbidimeter. Although the amount of HIV-1 RT-LAMP products was  
8 monitored by a real-time turbidimeter (LA-200) in the current study, the results of  
9 visual inspection were consistent with those determined by turbidimeter (data not  
10 shown). According to the manufacturer's instructions for the Loopamp DNA  
11 amplification kit, visual detection can be enhanced by the addition of Fluorescent  
12 Detection Reagent to the reaction mixture. Interestingly, HIV-1 RT-LAMP products of  
13 the two samples that were undetectable by LA-200 (01CM2219 and 01CM2232) could  
14 be visualized by adding the intercalating dye under UV irradiation, when the assay was  
15 carried out in the presence of Fluorescent Detection Reagent. Thus, the HIV-1 RT-  
16 LAMP assay has the advantage of enabling the amplification of HIV-1 RNA and/or  
17 DNA in resource-limited settings in which sophisticated machines such as the thermal  
18 cyclor and real-time turbidimeter are unavailable. In the two samples that were not  
19 detected by LA200, the production of magnesium pyrophosphate was prevented by  
20 unknown inhibitor(s). The cause and frequency of this phenomenon are under  
21 investigation.

1 RT-LAMP assay exhibits high specificity due to its use of multiple primers,  
2 including two loop primers, that recognize eight distinct regions of the target sequences.  
3 Previous studies in which RT-LAMP was used to detect various viral RNAs have  
4 documented the high specificity of RT-LAMP (Mori et al., 2006; Toriniwa et al., 2006;  
5 Ito et al., 2006; Okafuji et al., 2005; Parida et al., 2004; Hong et al., 2004; Poon et al.,  
6 2005; Fujino et al., 2005; Parida et al., 2005; Ushio et al., 2005). Similarly, HIV-1 RT-  
7 LAMP analysis of 40 sero-negative and PCR-negative samples showed 100%  
8 specificity, making the RT-LAMP assay ideal for confirming diagnosis.

9 The 100% detection limit of the HIV-1 RT-LAMP assay was found to be 120  
10 copies/ml (12 copies/100 µl/assay). This sensitivity is inferior to the quantification limit  
11 (50 copies/ml) of the UltraSensitive Assay of the COBAS AMPLICOR HIV-1  
12 MONITOR test, v 1.5 (Roche), but superior to the detection limit of the Standard Assay  
13 in the kit (400 copies/ml), and typical RT-PCR assays. Furthermore, the sensitivity of  
14 the current HIV-1 RT-LAMP could be improved to reach or exceed that of the  
15 UltraSensitive Assay by using a larger initial plasma sample (more than 240 µl) for  
16 extracting viral RNA.

17 The HIV-1 RT-LAMP assay was evaluated using 57 HIV-1 strains belonging to  
18 nine different group-M subtypes/CRFs and one group O based on *gag* and *pol*  
19 sequences, respectively (Table 1): subtypes A (n = 3), B (n = 6), F2 (n = 1), G (n = 1),  
20 CRF\_01AE (n = 8), CRF\_02.AG (n = 17), CRF\_09.cpx (n = 1), CRF\_11.cpx (n = 16),  
21 CRF\_13.cpx (n = 3), and group O (n = 1; Ndembi et al., 2004). This assay system

1 identified all of the 56 group-M HIV-1 strains despite their diversity, but did not detect  
2 the group-O strain, indicating that the primers used in the current HIV-1 RT-LAMP  
3 assay were group-M specific. Thus, in order to detect not only all of the HIV-1 groups  
4 but HIV type-2 strains as well, the design of universal primer set will be necessary.

5 Although the viral RNA extraction method used in this study is relatively easy and  
6 cheap as compared to conventional methods, it still requires knowledge and training not  
7 usually available in resource-limited settings. Therefore, it will be necessary to revise  
8 and simplify the extraction method in order to use this assay as a confirmatory test for  
9 HIV diagnosis in the field. Future evaluation of the direct use of plasma or serum after  
10 heating as a test material is warranted (Curtis et al., 2008).

11 In conclusion, a one-step RT-LAMP assay for detecting group-M HIV-1 has been  
12 developed. The RT-LAMP assay is simple, rapid, and highly sensitive and specific for  
13 group-M HIV-1; therefore, this assay can be used to confirm group-M HIV-1 diagnosis.  
14 Once the RNA extraction method is simplified, the group-M HIV-1 RT-LAMP assay  
15 will be ideal for use in resource-limited settings.

16

17

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21 and Welfare, Japan.

22

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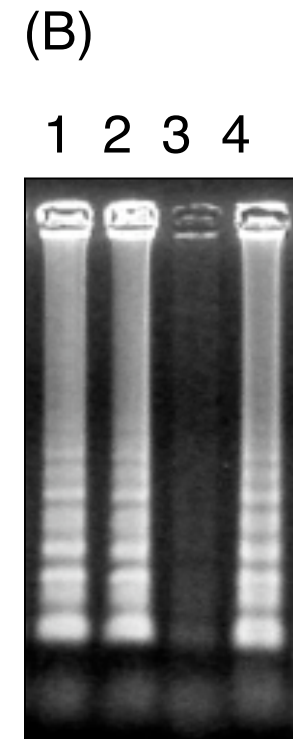
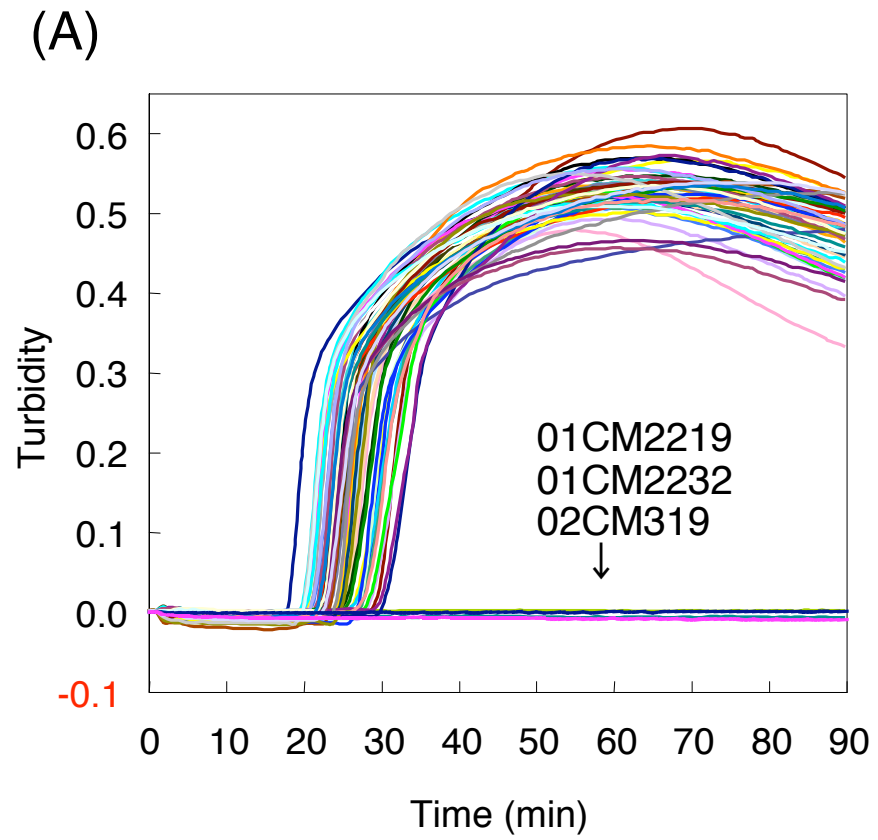
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- 5

1 **Figure captions**

2

3 Fig.1. Real-time detection of HIV-1 RT-LAMP products of 57 HIV-1-positive samples  
4 from Cameroon by turbidimeter (LA-200). (A) Agarose gel electrophoresis of HIV-1  
5 RT-LAMP products that were undetectable by LA-200. A turbidity value of more than  
6 0.1 was considered positive. Turbidity of three samples (01CM2219, 01CM2232, and  
7 02CM319) was less than 0.1. (B-C) Representative pictures of HIV-1 RT-LAMP  
8 products with (B) and without (C) Fluorescent Detection Reagent. (B) Lane 1:  
9 01CM2219; lane 2: 01CM2232; lane 3: 02CM319; and lane 4: 01CM2213 (positive  
10 control). (C) HIV-1 RT-LAMP positive (+) and negative (-). FDR: Fluorescent  
11 Detection Reagent; UV: ultraviolet irradiation.  
12

Fig. 1



(C)

Turbidity



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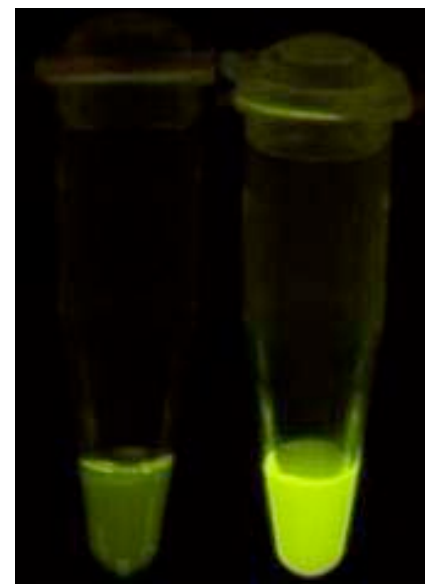
FDR



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FDR + UV



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TABLE 1. HIV-1 genotype data for 57 infected individuals from eastern Cameroon and the results of HIV-1 RT-LAMP.

Sample ID	Genetic subtype <sup>a</sup>				LAMP	
	<i>gag</i>	<i>pol</i>	<i>env</i> C2V3	<i>gp41</i>	Tt <sup>e</sup>	EP
01CM2213	CRF_01.AE	na <sup>c</sup>	CRF_01.AEA	na	19.2 <sup>f</sup>	P <sup>g</sup>
01CF2214	G	U	U	na	25.8	P
01CM2215	CRF_02.AG	na	CRF_02.AG	na	28.7	P
01CM2216	A	na	A	na	21.2	P
01CM2217	CRF_11.cpx	na	CRF_11.cpx	na	26.5	P
01CM2218	CRF_11.cpx	CRF_11.cpx	nd	U	31.0	P
01CM2219	CRF_11.cpx	na	CRF_02.AG	na	No Tt	P
01CM2220	CRF_02.AG	na	A	na	29.2	P
01CM2222	CRF_02.AG	na	CRF_02.AG	na	29.2	P
01CM2223	CRF_01.AE	na	CRF_02.AG	na	26.2	P
01CM2224	CRF_02.AG	na	CRF_02.AG	na	28.8	P
01CM2225	B	na	A	na	24.3	P
01CM2226	CRF_02.AG	na	CRF_02.AG	na	26.4	P
01CM2227	CRF_02.AG	na	CRF_02.AG	na	27.2	P
01CM2228	CRF_02.AG	na	CRF_02.AG	na	30.9	P
01CM2229	CRF_11.cpx	na	CRF_11.cpx	na	27.0	P
01CM2230	A	na	A	na	22.7	P
01CM2231	CRF_02.AG	na	A	na	23.4	P
01CM2232	B	U	A	U	No Tt	P

01CM2234	CRF_11.cpx	na	CRF_02.AG	na	26.0	P
01CM2235	B	U	nd	U	21.9	P
01CM2236	CRF_02.AG	na	CRF_02.AG	na	25.2	P
01CM2237	F2	na	F2	na	25.1	P
01CM2238	CRF_13.cpx	na	CRF_01.AE	na	22.2	P
01CM2239	CRF_13.cpx	na	CRF_11.cpx	na	26.2	P
01CM2240	CRF_02.AG	na	CRF_13.cpx	na	29.6	P
01CM2241	CRF_01.AE	CRF_11cpx	nd	U	27.5	P
01CM2242	CRF_02.AG	na	CRF_02.AG	na	24.8	P
01CM2243	CRF_11.cpx	CRF_11cpx	nd	CRF_11.cpx	24.7	P
01CM2244	CRF_01.AE	na	CRF_11.cpx	na	23.1	P
01CM2246	B	na	CRF_01.AE	na	23.6	P
01CF2247	CRF_11.cpx	na	CRF_01.AE	na	24.1	P
01CM2248	CRF_01.AE	na	A	na	21.9	P
01CM2249	A	na	A	na	23.6	P
01CM2250	CRF_02.AG	CRF_02.AG	nd	U	30.5	P
01CM2252	CRF_02.AG	U	nd	U	28.6	P
01CM2253	CRF_01.AE	U	nd	A	21.7	P
01CM2256	CRF_01.AE	na	A	na	21.6	P
01CM2257	CRF_01.AE	na	A	na	21.9	P
01CM2260	CRF_13.cpx	U	A	CRF_13.cpx	23.7	P
01CM2262	B	na	CRF_02.AG	na	27.8	P
01CF2268	CRF_02.AG	CRF_02.AG	nd	CRF_02.AG	32.5	P

01CM2269	CRF_11.cpx	CRF_11.cpx	nd	CRF_11.cpx	26.7	P
01CM2270	CRF_02.AG	CRF_02.AG	nd	U	31.9	P
01CM2271	CRF_11.cpx	CRF_02.AG	nd	CRF_11.cpx	23.9	P
01CM2272	CRF_11.cpx	na	CRF_11.cpx	na	21.2	P
01CM2273	CRF_11.cpx	na	CRF_11.cpx	na	25.5	P
01CM2274	CRF_02.AG	na	CRF_02.AG	na	22.6	P
01CM2275	CRF_09.cpx	CRF_02.AG	nd	CRF_09.cpx	24.5	P
01CM2276	CRF_11.cpx	na	CRF_11.cpx	na	23.9	P
01CM2277	CRF_11.cpx	CRF_11.cpx	nd	CRF_11.cpx	21.4	P
01CM2278	B	na	CRF_02.AG	na	24.2	P
01CM2280	CRF_11.cpx	CRF_02.AG	nd	CRF_02.AG	29.8	P
01CM2281	CRF_02.AG	CRF_02.AG	nd	CRF_02.AG	23.4	P
01CM2284	CRF_11.cpx	CRF_11.cpx	nd	CRF_11.cpx	24.5	P
01CM2287	CRF_11.cpx	na	CRF_01.AE	na	33.2	P
02CM319	nd <sup>b</sup>	O <sup>d</sup>	nd	O	No Tt	N <sup>h</sup>

<sup>a</sup> Genotyping based on part of *gag*-p24 (460 bp), *env*-C2V3 (approximately 550 bp), *pol*-integrase, and *env*-gp41 (approximately 405 bp) regions; <sup>b</sup> not detected; <sup>c</sup> not available; <sup>d</sup> Group O; <sup>e</sup> threshold time by LA-200; <sup>f</sup> agarose gel electrophoresis; <sup>g</sup> positive; and <sup>h</sup> negative.



TABLE 2. Sequences of primers used for HIV-1 RT-LAMP

Primer Name	Sequence	Genome Position*
F3	5'-GGTAAGAGATCAGGCTGAACATC-3'	4721-4743
F2	5'-AGACAGCAGTACAAATGGCA-3'	4747-4766
Loop F	5'-TTAAAATTGTGGATGAAT-3'	4786-4769
F1c	5'-CCCCAATCCCCCCTTTTCTT-3'	4806-4787
B1c	5'-AGTGCAGGGGAAAGAATAGTAGAC-3'	4812-4835
Loop B	5'-GCAACAGACATACAAACTAAAG-3'	4842-4863
B2	5'-CTGCTGTCCCTGTAATAAACCC-3'	4921-4900
B3	5'-GCTGGTCCTTTCCAAAGTGG-3'	4945-4926
FIP	F1c + F2	
BIP	B1c + B2	

\* in HIV-1<sub>HXB2</sub>