

Inactivation and Survival of Hepatitis C Virus on Inanimate Surfaces

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Background. Hepatitis C virus (HCV) cross-contamination from inanimate surfaces or objects has been implicated in transmission of HCV in health-care settings and among injection drug users. We established HCV-based carrier and drug transmission assays that simulate practical conditions to study inactivation and survival of HCV on inanimate surfaces.

Methods. Studies were performed with authentic cell culture derived viruses. HCV was dried on steel discs and biocides were tested for their virucidal efficacy against HCV. Infectivity was determined by a limiting dilution assay. HCV stability was analyzed in a carrier assay for several days or in a drug transmission assay using a spoon as cooker.

Results. HCV can be dried and recovered efficiently in the carrier assay. The most effective alcohol to inactivate the virus was 1-propanol, and commercially available disinfectants reduced infectivity of HCV to undetectable levels. Viral infectivity on inanimate surfaces was detectable in the presence of serum for up to 5 days, and temperatures of about 65–70°C were required to eliminate infectivity in the drug transmission assay.

Conclusions. These findings are important for assessment of HCV transmission risks and should facilitate the definition of stringent public health interventions to prevent HCV infections.

Hepatitis C virus (HCV) is an enveloped virus that, at present, chronically infects ~130 million people worldwide [1]. One hallmark of HCV is its high degree of sequence variability, which likely contributes to its ability to establish chronic infections. Different patient isolates are grouped into 7 genotypes and more than 100 subtypes within the genus *Hepacivirinae* of the family *Flaviviridae* [2]. Persistent infection is associated with a variable degree of liver damage often progressing in severity over the course of decades. Accordingly, a large number of patients are at risk of severe sequelae including life-threatening conditions like cirrhosis and

hepatocellular carcinoma [3]. The best available treatment, a combination of polyethylene glycol (PEG)-conjugated interferon alpha (IFN- α) and ribavirin, is not effective in every patient and can be associated with severe adverse effects [4]. A prophylactic or therapeutic vaccine is so far not available.

Hepatitis C is a blood-borne viral infection transmitted mainly through intravenous drug use, blood transfusions, accidental needle sticks, and other parental exposures, including nosocomial transmissions [5–9]. With the implementation of routine testing of blood products for HCV, transfusion-transmitted infections became rare [10]. However, outbreaks in health-care settings have been consistently reported primarily attributed to contaminated medications or equipment and breaches in aseptic techniques in the United States, Europe, and Japan [11–15]. Furthermore, cross-contamination continues to occur among injection drug users (IDUs) by the sharing of drug preparation equipment [16–18]. The seroprevalence of HCV among IDUs in the United States is high, ranging between 30% and 85%, with current estimates suggesting more than

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over 60% of newly acquired infections occur in individuals who have injected drugs [19, 20]. The adequate assessment of transmission risks and the evaluation of the mechanisms of transmission have been difficult due to the lack of cell culture systems and animal models permissive to HCV infection. This obstacle has been overcome with the development of an HCV cell culture system based on the Japanese fulminant hepatitis (JFH1) HCV isolate, which reproduces the complete viral replication cycle in vitro [21–23]. This infection system was recently applied to evaluate the environmental stability of HCV and its susceptibility to chemical biocides in liquid suspensions [24]. Furthermore, Paintsil et al [25] analyzed in 2010 the survival of HCV in contaminated syringes and the duration of potential infectiousness; however, both studies did not analyze viability and infectivity of dried HCV.

Therefore, simulating realistic practical conditions, we established an HCV-based carrier and drug transmission assay to test inactivation and stability of HCV on inanimate surfaces. These results allow the further exploration of viral transmission from contaminated surfaces, objects, or devices and the potential for recommendations for effective measures interrupting this transmission.

MATERIALS AND METHODS

Plasmids and Viruses

The plasmid pFK-Jc1 has been described recently [26]. Construct Luc-Jc1 encodes a chimeric HCV polyprotein that consists of codons 1–846 derived from J6/CF [27] combined with codons 847–3033 of JFH1. In this genome the HCV polyprotein-coding region is located in the second cistron and is expressed via an internal ribosomal entry site element derived from the encephalomyocarditis virus. The first cistron contains the firefly luciferase reporter gene fused to the JFH1-derived 5'NTR and coding region of the N-terminal 16 amino acids of JFH1 core [28].

Chemical Biocides

The alcohol substances 1-propanol, 2-propanol and ethanol were purchased from Carl Roth, Karlsruhe, Germany. Six commercially available biocides for surface disinfection were chosen to study the efficacy against dried HCV: Product A (based on ethanol, 2-propanol), product B (based on ethanol, 1-propanol), product C (based on glutaraldehyde), product D and E (based on quaternary ammonium compounds), and product F (based on peroxide compounds).

Cell Culture

Huh7.5 cells were cultured in Dulbecco modified Eagle medium (DMEM, Invitrogen) with 10% fetal bovine serum, 1× non-essential amino acids (Invitrogen), 100 µg/mL streptomycin (Invitrogen) and 100 IU/mL penicillin (Invitrogen).

In Vitro Transcription, Electroporation, and Production of Cell Culture-Derived HCV

Infectious HCV particles were produced as described elsewhere [28]. Briefly, Jc1 or Luc-Jc1 plasmid DNA was linearized and transcribed into RNA, which was then electroporated into Huh7.5 cells. Virus-containing culture fluids were harvested after 48 or 72 hours filtered through a 0.45 µm pore size filter. For determination of viral infectivity cell-free supernatants were used to infect naive Huh7.5 target cells.

Determination of HCV Infectivity

Titers of infectious virus were determined by using a limiting dilution assay on Huh7.5 cells with a few minor modifications and tissue culture infectious dose 50 (TCID₅₀) was determined as described elsewhere [23]. For determination of Luc-Jc1 reporter activity, infected cells were washed with phosphate-buffered saline (PBS) and lysed in luciferase lysis buffer (1 % Triton X-100, 25 mmol/L glycylglycine, 15 mmol/L MgSO₄, 4 mmol/L EGTA, and 1 mmol/L DTT, pH 7.8). Firefly luciferase activity was measured as described previously [28].

Preparation of the Carrier

Stainless steel discs with grade 2B finish on both sides (20 mm diameter, GK Formblech GmbH) were incubated in a 5% (vol/vol) Decon 90-solution (Decon Laboratories Ltd) for 1 hour. Afterward the discs were rinsed off twice with freshly distilled water for 10 seconds, ensuring that the carriers did not dry to any extent, and were then placed in 70% ethanol (vol/vol) for 15 minutes. Finally, the carriers were dried by evaporation in sterile petri dishes under a biological safety cabinet.

Experimental Procedure of HCV Carrier Assay

In total, 50 µL of the virus inoculum were pipetted in the center of each pretreated carrier and dried in a desiccator or under a laminar flow for about 1–3 hours at room temperature. After drying, the virus contaminated discs were transferred with forceps into 25 mL plastic vial holders (Sarstedt AG & Co KG), which were previously filled with 0.5 g of sterile glass beads (0.25–0.50 mm diameter, Carl Roth GmbH) to increase virus recovery by mechanical abrasion. Then, 100 µL of the test substance were pipetted on the dried virus inoculum and incubated for 1 or 5 minutes. Control carriers received 100 µL of water instead of the chemical biocide. In order to neutralize the test substance, 900 µL of culture medium were immediately added at the end of the chosen exposure time. The vials were directly vortexed for 1 minute to recover the residual virus, before the eluate was diluted to measure viral infectivity. To determine cytotoxicity of the biocides, 1 part of PBS was mixed with 9 parts of the biocide and used to inoculate, permissive Huh7.5 cells. Cytotoxicity was determined by examining permissive cells by microscopy for any significant changes in the cell monolayer and calculated analogously to virus titer (TCID₅₀/mL).

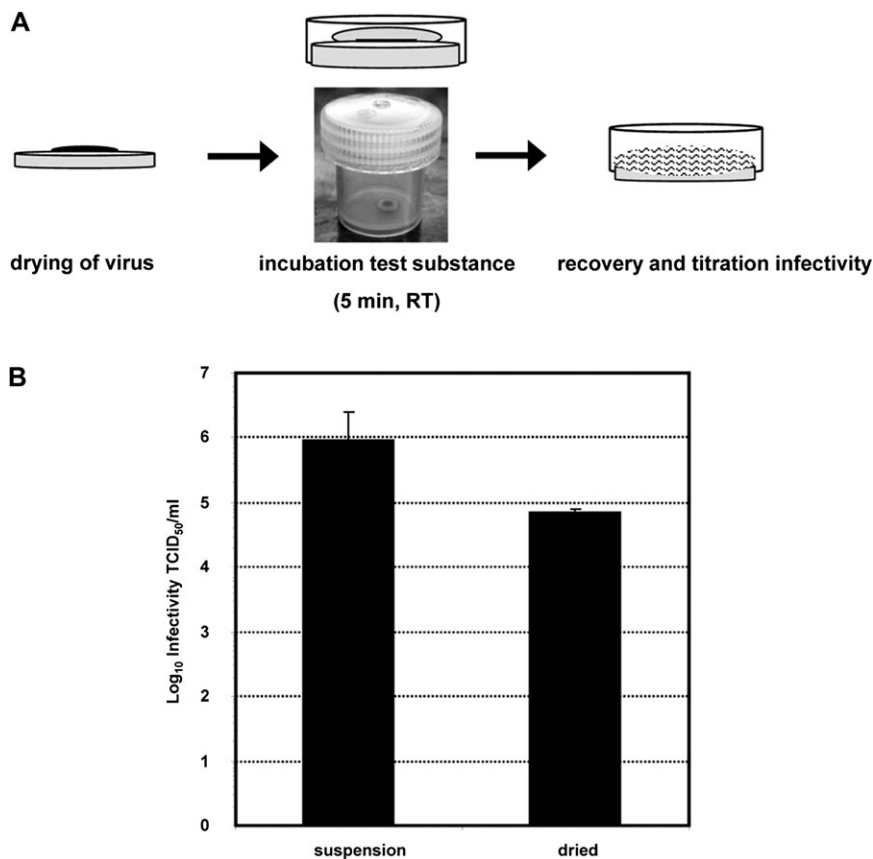


Figure 1. Experimental setup for hepatitis C virus (HCV) carrier assay. *A*, Stainless steel discs were inoculated with 50 μ L of Jc1 and dried under a laminar flow for about 1 hour. After drying, discs were transferred into 25 mL plastic vial holders, which were previously filled with glass beads. Biocides for testing were distributed onto the dried virus and incubated for 1 or 5 minutes. In total, 900 μ L of culture medium were immediately added at the end of the exposure time. The vials were directly vortexed for 1 minute, before the eluate was diluted to determine viral infectivity by immunohistochemistry. *B*, Jc1 virus was either incubated in suspension or dried on a carrier disc for 1 hour before viral titers were determined by a limiting dilution assay. Viral titers are displayed as 50% tissue culture infective dose 50 (TCID₅₀) values. The mean values of 8 independent experiments with standard errors are shown.

For testing HCV stability and inactivation in the presence of serum, whole blood samples of healthy donors were centrifuged for 5 minutes at 5000 rpm to obtain serum. The effect of serum on HCV stability was tested by mixing serum and virus suspension in a ratio 1:1 in a total volume of 0.1 mL before the drying procedure.

Experimental Procedure for HCV Drug Transmission Assay

To test the effect of different temperatures on HCV infectivity in a drug preparation simulation, viral suspensions of 800 μ L were used as inoculum of a standard household spoon (stainless steel). A heating procedure was started with a tea candle with a distance of \sim 4 cm between the spoon and the top of the flame. Temperatures of the suspensions were measured at specific time intervals using a thermometer for small liquids (YEW pocket thermometer 2542). At given temperatures, 70 μ L of the viral suspension was sampled. To judge the influence of human serum on virus stability in the drug transmission assay, virus suspension was diluted in a ratio of 1:8 with serum or water.

Viral infectivity was determined by a luciferase reporter assay as described elsewhere [28].

RESULTS

Development of a HCV-Based Carrier Test

In general, the carrier test method is designed to evaluate the ability of chemical biocides to inactivate vegetative bacteria, viruses, fungi, mycobacteria and bacterial spores on inanimate surfaces [29]. Here, the experimental procedure of the carrier assay was used for the first time to test the virucidal activity of biocides against dried HCV. First, stainless steel discs were inoculated with a virus preparation of the HCV genotype 2a chimera Jc1 [26] and dried under a laminar flow (Figure 1A). After drying, the virus-contaminated discs were transferred into plastic vial holders, which were previously filled with glass beads to increase virus recovery by mechanical abrasion. Next, the tested biocides were distributed onto the dried virus and incubated for 1 or 5 minutes. In order to neutralize the test

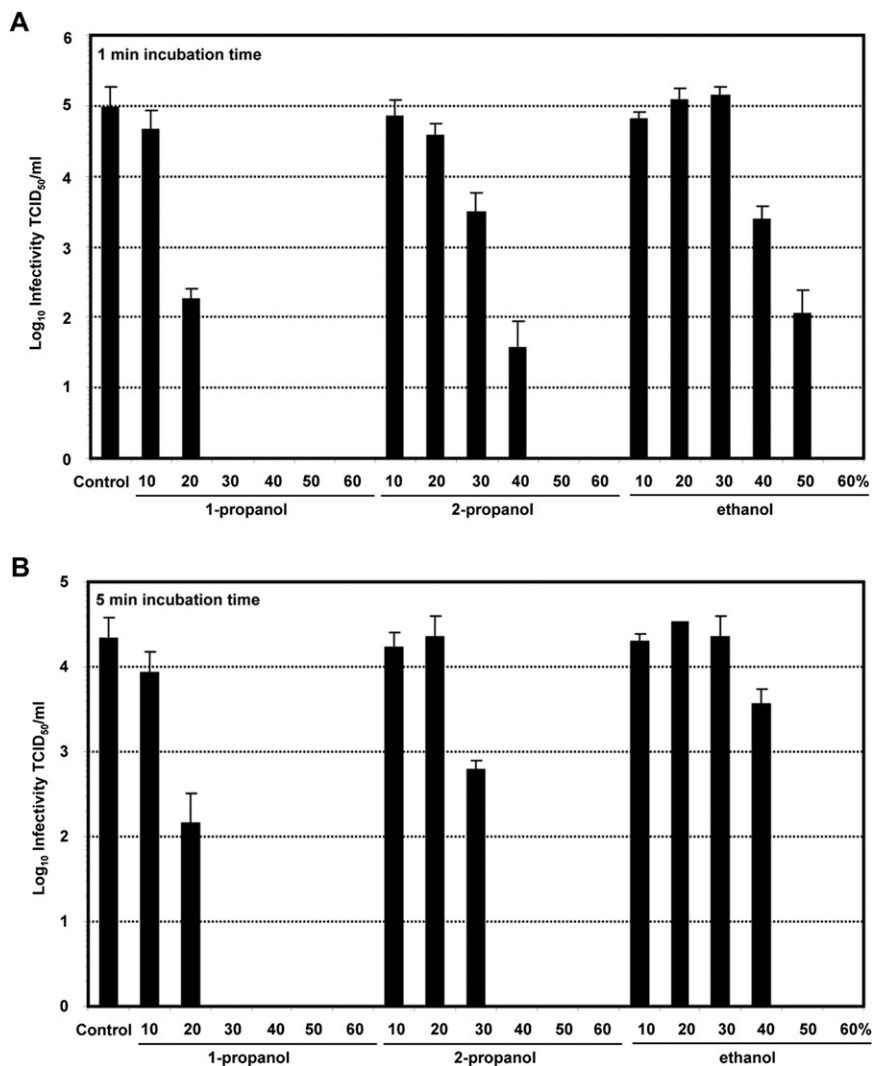


Figure 2. Effect of different kinds of alcohol against hepatitis C virus (HCV). *A*, 1-propanol, 2-propanol, and ethanol were tested in a carrier assay for their efficacy in inactivating HCV. The alcohol concentrations ranged from 10% to 60% with an exposure time of 1 minute. Residual infectivity was determined by a limiting dilution assay. Viral titers are displayed as 50% tissue culture infective dose 50 (TCID₅₀) values. The mean values of 2 independent experiments with standard errors are shown. *B*, Different alcohols were tested in a carrier assay for their efficacy in inactivating HCV as described in panel *A* with an exposure time of 5 minutes. The mean values of 3 independent experiments with standard errors are shown.

substance, culture medium was immediately added at the end of the exposure time. The vials were directly vortexed to recover residual infectivity, before the eluate was diluted to determine viral infectivity using a limiting dilution assay.

It has been described that depending on which virus type is dried on the carrier the amount of infectivity recovered might vary [29]. Therefore, to determine the recovery efficiency for HCV, we titrated Jc1 incubated 1 hour in suspension and a virus inoculum that was dried for the same time on a carrier disc. As depicted in Figure 1*B*, the infectivity of HCV recovered from the carrier surface by our procedure was about 10-fold lower compared with the HCV stored in a liquid environment. Thus, ~10% of the viral infectivity was recovered in the carrier assay.

Virucidal Efficacy of 1-Propanol, 2-Propanol, and Ethanol Against Dried HCV

Surface disinfectants used in health care and other medical settings often contain 1-propanol, 2-propanol or ethanol as active ingredients for decontamination of surfaces. To assess the virucidal efficacy of these alcohols at concentrations ranging from 10% to 60% on contaminated surfaces, we incubated each alcohol for 1 minute (Figure 2*A*) and 5 minutes (Figure 2*B*) on dried HCV. The most effective alcohol to inactivate HCV was 1-propanol, reducing viral titers to background levels at a concentration of 30% with both incubation times (Figure 2). For 2-propanol, a concentration of 30% decreased infectivity about 10-fold, and complete inactivation was observed at an alcohol

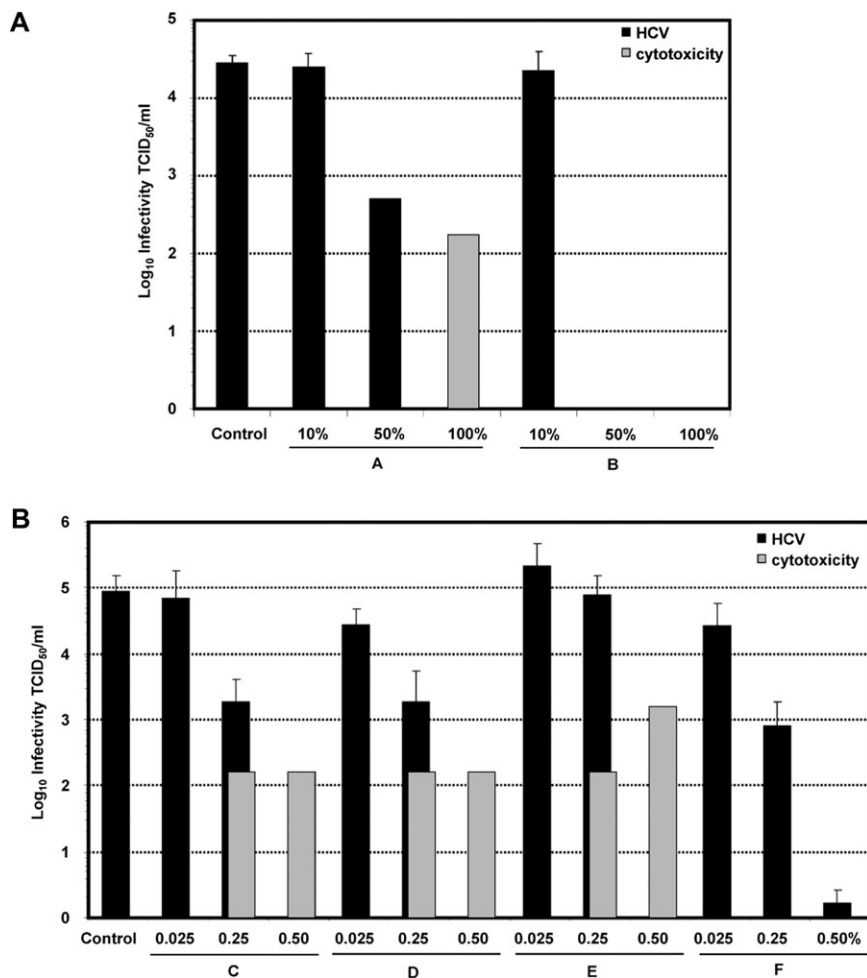


Figure 3. Effect of commercial surface disinfectants against hepatitis C virus (HCV). *A*, Two alcohol-based commercial surface disinfectants (products A and B) were tested in a carrier assay for their virucidal efficacy against HCV. Concentrations of 10%, 50%, and 100% were used with an exposure time of 5 minutes. Residual infectivity was determined by a limiting dilution assay. Viral titers are displayed as 50% tissue culture infective dose 50 (TCID₅₀) values. The mean values of 3 independent experiments with standard errors are shown. *B*, Four commercial surface disinfectants (products C–F) were tested in a carrier assay for their virucidal efficacy against HCV as described in panel (*A*) with concentrations of 0.025%, 0.25%, and 0.5%. The mean values of 3 independent experiments with standard errors are shown.

content of 50% with a 1-minute exposure time and 40% with 5 minutes incubation, respectively. Ethanol showed the lowest virucidal efficacy with a required concentration of 50% to reduce viral titers to undetectable levels in the 5-minute exposure (Figure 2*B*).

Effect of Commercially Available Surface Disinfectants Against Dried HCV

To directly determine the efficacy of commercially available surface disinfectants, we chose 6 different chemical biocides with different virucidal substances as ingredients. Products A and B were both based on ethanol and 2-propanol or 1-propanol, respectively. Product C contained glutaraldehyde as active ingredient. Product D and E were on the basis of quaternary ammonium compounds, whereas for product F peroxide compounds were used as virucidal substance. The alcohol-based biocides were tested as recommended with an incubation time

of 5 minutes in the concentrations of 10%, 50%, and 100%. As depicted in Figure 3*A*, a concentration of 50% for product A reduced viral titers about 50-fold. In an undiluted preparation no infectivity could be detected; however, at a 100% concentration also cytotoxicity was visible. Product B containing ethanol and 1-propanol demonstrated a higher virucidal efficacy than product A reducing viral titers to background levels already at a concentration of 50%, thus confirming the previous results that 1-propanol is superior over 2-propanol as biocide for HCV. The other commercially available disinfectants were tested at concentrations of 0.025%, 0.25%, and 0.5% in the carrier test (Figure 3*B*). A complete inactivation could be achieved by all products at the highest concentration with only slight cytotoxicity for products C, D, and E. These results show that ingredients like glutaraldehyde, quaternary ammonium, and peroxide compounds have a high virucidal efficacy against HCV.

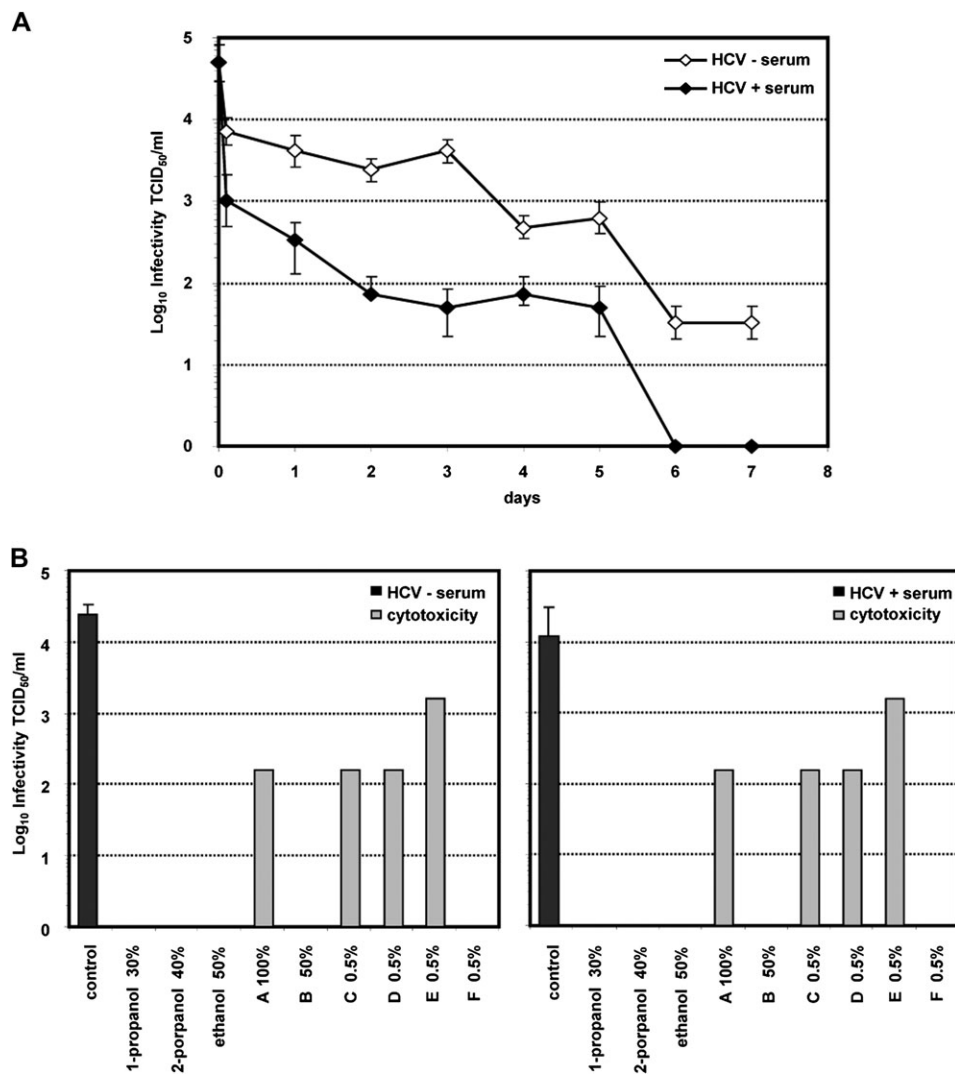


Figure 4. Stability of dried hepatitis C virus. *A*, Jc1 in the presence or absence of human serum was dried on a carrier and incubated for several days at room temperature at indicated time points. Infectivity was determined by a limiting dilution assay. A representative experiment with 3 independent repetitions is shown. *B*, Different biocides at indicated concentrations and exposure time of 5 minutes were tested in a carrier assay for their efficacy in inactivating HCV in the presence or absence of human serum. Residual infectivity was determined by a limiting dilution assay. Viral titers are displayed as 50% tissue culture infective dose 50 (TCID₅₀) values. The mean values of 3 independent experiments with standard errors are shown.

Survival of Dried HCV on Inanimate Surfaces

Recently, it could be shown that HCV can be stable for several weeks in a liquid environment or in syringes [24, 25]. To evaluate the stability of nonliquid HCV, Jc1 virus was dried on carrier discs and incubated for several days at room temperature. As HCV infection is typically transmitted via blood, the effect of healthy serum on the stability of dried HCV was analyzed in parallel. Infectivity of dried virus in the presence of serum was reduced 10-fold after 2 days and reached undetectable levels after 6 days. Furthermore, the addition of serum resulted in reduced viral titers compared with the virus without serum (Figure 4A). In the latter case, we still could measure infectious HCV with a titer of about 30 TCID₅₀/mL after 7 days of incubation demonstrating a stability of dried HCV for more than

a week on the carrier surface. In the next set of experiments, we analyzed if the addition of serum before the drying procedure influences the ability of the different biocides to inactivate HCV as reported for other viruses. The different alcohols or commercial disinfectants that were used in a concentration completely inactivated HCV as shown before (compare Figures 2 and 3). All tested biocides were able to inactivate HCV infectivity to undetectable levels in the presence or absence of serum (Figure 4B), indicating that serum cannot confer viral resistance to the tested biocides.

Heat Stability of HCV in a Drug Transmission Assay

Epidemiologic studies indicate that the sharing of the drug preparation equipment among IDUs is an important risk factor

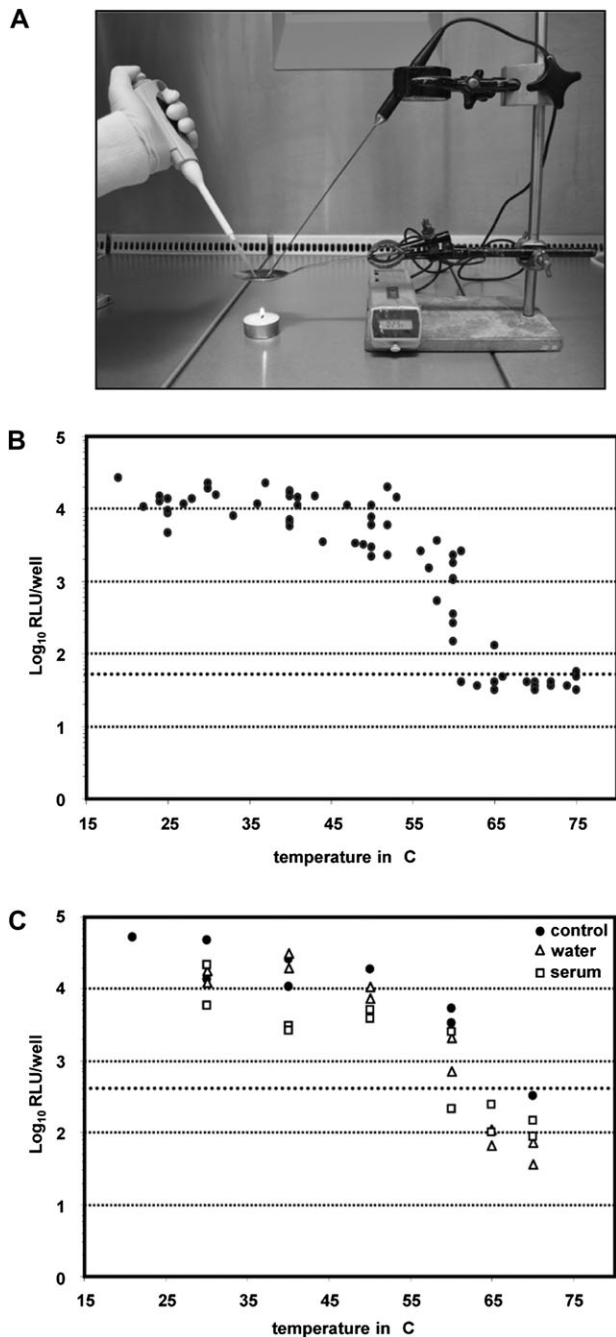


Figure 5. Hepatitis C virus stability on equipment for heating drugs into solution. *A*, For the drug transmission assay, viral suspensions of 800 μ L were used as inoculum of a spoon as cooker. A heating procedure was started with a tea candle. Temperatures of the suspensions were measured at specific time intervals, and at given temperatures 70 μ L of the viral suspension was sampled. Infectivity was determined by infection of naive Huh7.5 cells following luciferase reporter assay. *B*, Luc-Jc1 reporter virus was incubated at the indicated temperatures as a viral suspension with a volume of 800 μ L on a spoon. Temperatures increased by the use of a tea candle. Infectivity of 70 μ L aliquots was determined by infection of naive Huh7.5 cells following luciferase reporter assay. The values of 9 independent measurement series are shown. *C*, Luc-Jc1 reporter virus was incubated on a spoon as described in panel *A*. Water and serum were added in a dilution of 1:8 with the virus suspension

for HCV transmission [18, 30]. Spoons and/or cookers are used to heat diluted heroin into solution. Cookers are mostly used in the United States, whereas spoons are mostly used in Europe. During the drug preparation, spoons are often reused and shared between users. The drug dilution from the spoon is drawn into a syringe, and blood contaminated with HCV can be exposed to the drug dilution by insertion of an HCV-contaminated syringe into spoons that are shared. Therefore, blood on spoons/cookers could be source for contamination with infectious HCV, and the ability of the virus to survive on such surfaces can have a strong impact on cross-transmissions. To evaluate the transmission risk via this route, we contaminated a spoon with Jc1 reporter virus (Figure 5A). With the use of a tea candle, increasing temperatures were simulated with the cooker device. At indicated time intervals, aliquots were taken and used to determine infectivity by luciferase reporter assay. Viral infectivity started to decrease at a temperatures of $\sim 50^{\circ}\text{C}$ and was below the detection limit at about $65\text{--}70^{\circ}\text{C}$ in 9 independent measurement series (Figure 5B). The time required to reach certain temperatures depends highly on the experimental setup, but in our case $\sim 80\text{--}95$ seconds were necessary when small bubbles start to appear on the spoon. The half-life of HCV at different temperatures did not differ significantly between reporter virus and authentic wild-type HCV Jc1 (data not shown). Next, we tested the impact of water and serum in this drug transmission assay. As depicted in Figure 5C, the addition of water or serum to the virus solution did not influence HCV stability. Again, $\sim 65^{\circ}\text{C}$ was the temperature required to inactivate viral infectivity to background levels.

DISCUSSION

For better understanding and prevention of HCV transmission in medical settings and in the environment, experimental system simulating practical conditions are highly relevant. In this study, we addressed HCV inactivation and stability profiles on inanimate surfaces to mimic viral cross-transmissions among IDUs and in health-care settings where HCV infections continue to occur. We demonstrated that HCV could be dried and recovered efficiently in a carrier assay that can therefore be used to validate chemical biocides in their virucidal efficacy against HCV. Importantly, it also confirms that reusing HCV contaminated cookers could lead to infection even if using sterile syringes. Furthermore, by simulating the procedure for heating drugs into solution, we showed that HCV could be eliminated at temperatures of $65\text{--}70^{\circ}\text{C}$. These data can be used for the design

before temperatures were increased by the use of a tea candle. Infectivity of 70 μ L aliquots was determined by infection of naive Huh7.5 cells following luciferase reporter assay. The values of at least 2 independent measurement series are shown.

of public health recommendations and prevention of viral spread among IDUs. Until recently, experimental data about the environmental stability of HCV were not reported or performed with surrogate markers (antigens, RNA, enzyme activity) for the presence or absence of infectious particles. The HCV infection system used here is based on human hepatoma cells and viruses generated *in vitro* [21–23], and substantial progress has been made in HCV basic and translational research with this model [31]. However, limitations are that *in vivo* hepatocytes and patient-derived particles might be slightly different or that not all genotypes can be grown in cell culture.

In the environment, viruses are normally found on surfaces and/or embedded in body fluids like excrements, serum, blood, or other excretions, and the risk of viral transmission depends on the contact number, time, body parts, and how readily the virus is released from such surfaces. The carrier test method for HCV developed here allows predicting the activity of chemical biocides simulating practical conditions. Dried HCV was exposed to a test product for a defined contact time. At the end of the contact time, the virus-biocide mixture was recovered from the surface of the carrier and titrated to determine the degree of loss in virus infectivity. We could previously show in a quantitative suspension assay that 1-propanol is the most effective alcohol in activating HCV [24]. However, whereas in a suspension test a concentration of 20% 1-propanol was sufficient to eliminate Jc1 with a viral titer of 10^6 TCID₅₀/mL, higher concentration of the alcohol are needed to inactivate dried HCV due to a stronger challenge for the disinfectant [29]. Importantly, we could demonstrate that commercially available surface disinfectants have a high virucidal efficacy at concentrations recommended by the manufacturers as previously shown for hand antiseptics [24]. While dried virus in the presence of serum could survive for up to 5 days at room temperature, we could show that HCV in suspension could survive for even 3 weeks [24], and in syringes infectivity was detected for up to 63 days [25]. Kamili and colleagues [32] demonstrated in a chimpanzee animal model that dried HCV derived from patient sera could survive for at least 16 hours but was not detectable after storage of 4 or 7 days. Differences in the viral dose, storage conditions, or determination of infectivity *in vitro* or *in vivo* [33, 34] might account for the different survival times between these studies. We used here a highly sensitive detection assay and were able to determine precise survival times of the virus on dried surfaces in the presence or absence of serum. The transmission patterns for hepatitis B virus (HBV) are very similar to HCV, and high stability in the environment has been reported for this hepatotropic virus as well [35]. In line with our results, infectivity after drying of HBV-positive human plasma could be detected for at least 1 week while no longer incubation times were analyzed [35]. In summary, these reports showed that HCV could remain viable for a prolonged time in the environment indicating that blood-contaminated surfaces can serve as HCV reservoirs.

Consequently, effective disinfection of surfaces is crucial in the prevention of HCV transmission.

Transmission of HCV remains high among IDUs in recent years, with incidence rates ranging from 16% to 42% per year [36]. Furthermore, the risk of HCV transmission estimated per exposure to a contaminated syringe is 5-fold to 20-fold higher than that of HIV [37–39]. Recently, Painsil et al [25] contributed to the understanding of biological mechanisms of HCV transmission by studying contaminated syringes with HCV cell culture derived virus [40]. They found that HCV survival was dependent on syringes type, time, and temperature. Infectivity could be detected for up to 63 days in high void volume tuberculin syringes. These results suggest that this long survival contributes to the high prevalence of HCV in comparison to HIV among IDUs in spite of successful syringe exchange programs. Besides syringes, the sharing of drug cookers and cotton for filtration was also significantly associated with HCV infection independent of sharing needles and syringes [18, 30]. We show here that HCV on a spoon as cooker can survive temperatures up to 65°C, which corresponds to a heating time of 80–95 seconds in this assay setup, indicating that virus survival on cookers could also be a potential source of infectious HCV aside from syringes.

In summary, we show that infectious HCV can persist as a dried sample for up to 1 week. The most effective alcohol to inactivate the virus was 1-propanol, and commercially available disinfectants reduced HCV infectivity to undetectable levels, emphasizing strict hygiene measurements. These experimental developments should facilitate testing the virucidal activity against HCV of chemical biocides used for surface disinfection. In addition, these results will further improve the understanding of HCV cross-contaminations and its prevention in health-care settings and among injection drug users.

Notes

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Potential conflicts of interest. All authors: No reported conflicts.

All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

References

- Alter MJ. Epidemiology of hepatitis C virus infection. *World J Gastroenterol* 2007; 13:2436–41.

2. Simmonds P, Bukh J, Combet C, et al. Consensus proposals for a unified system of nomenclature of hepatitis C virus genotypes. *Hepatology* **2005**; 42:962–73.
3. Hoofnagle JH. Hepatitis C: the clinical spectrum of disease. *Hepatology* **1997**; 26:15S–20S.
4. Manns MP, Wedemeyer H, Cornberg M. Treating viral hepatitis C: efficacy, side effects, and complications. *Gut* **2006**; 55:1350–9.
5. Esteban JI, Gomez J, Martell M, et al. Transmission of hepatitis C virus by a cardiac surgeon. *N Engl J Med* **1996**; 334:555–60.
6. Macedo de Oliveira A, White KL, Leschinsky DP, et al. An outbreak of hepatitis C virus infections among outpatients at a hematology/oncology clinic. *Ann Intern Med* **2005**; 142:898–902.
7. Williams IT, Perz JF, Bell BP. Viral hepatitis transmission in ambulatory health care settings. *Clin Infect Dis* **2004**; 38:1592–8.
8. Murphy EL, Bryzman SM, Glynn SA, et al. Risk factors for hepatitis C virus infection in United States blood donors. NHLBI Retrovirus Epidemiology Donor Study (REDS). *Hepatology* **2000**; 31:756–62.
9. Detering K, Wiegand J, Gruner N, Wedemeyer H. Medical procedures as a risk factor for HCV infection in developed countries: do we neglect a significant problem in medical care? *J Hepatol* **2008**; 48:1019–20; author reply 1020–1.
10. Busch MP, Wilber JC, Johnson P, Tobler L, Evans CS. Impact of specimen handling and storage on detection of hepatitis C virus RNA. *Transfusion* **1992**; 32:420–5.
11. Comstock RD, Mallonee S, Fox JL, et al. A large nosocomial outbreak of hepatitis C and hepatitis B among patients receiving pain remediation treatments. *Infect Control Hosp Epidemiol* **2004**; 25:576–83.
12. Krause G, Trepka MJ, Whisenhunt RS, et al. Nosocomial transmission of hepatitis C virus associated with the use of multidose saline vials. *Infect Control Hosp Epidemiol* **2003**; 24:122–7.
13. Lagging LM, Aneman C, Nenonen N, et al. Nosocomial transmission of HCV in a cardiology ward during the window phase of infection: an epidemiological and molecular investigation. *Scand J Infect Dis* **2002**; 34:580–2.
14. Forns X, Martinez-Bauer E, Feliu A, et al. Nosocomial transmission of HCV in the liver unit of a tertiary care center. *Hepatology* **2005**; 41:115–22.
15. Silini E, Locasciulli A, Santoleri L, et al. Hepatitis C virus infection in a hematology ward: evidence for nosocomial transmission and impact on hematologic disease outcome. *Haematologica* **2002**; 87:1200–8.
16. Thorpe LE, Ouellet LJ, Hershov R, et al. Risk of hepatitis C virus infection among young adult injection drug users who share injection equipment. *Am J Epidemiol* **2002**; 155:645–53.
17. Koester S, Glanz J, Baron A. Drug sharing among heroin networks: implications for HIV and hepatitis B and C prevention. *AIDS Behav* **2005**; 9:27–39.
18. Hagan H, Thiede H, Weiss NS, Hopkins SG, Duchin JS, Alexander ER. Sharing of drug preparation equipment as a risk factor for hepatitis C. *Am J Public Health* **2001**; 91:42–6.
19. Alter MJ. Prevention of spread of hepatitis C. *Hepatology* **2002**; 36:S93–8.
20. Shapshak P, Somboonwit C, Drumright LN, et al. Molecular and contextual markers of hepatitis C virus and drug abuse. *Mol Diagn Ther* **2009**; 13:153–79.
21. Zhong J, Gastaminza P, Cheng G, et al. Robust hepatitis C virus infection in vitro. *Proc Natl Acad Sci U S A* **2005**; 102:9294–9.
22. Wakita T, Pietschmann T, Kato T, et al. Production of infectious hepatitis C virus in tissue culture from a cloned viral genome. *Nat Med* **2005**; 11:791–6.
23. Lindenbach BD, Evans MJ, Syder AJ, et al. Complete replication of hepatitis C virus in cell culture. *Science* **2005**; 309:623–6.
24. Ciesek S, Friesland M, Steinmann J, et al. How stable is the hepatitis C virus (HCV)? Environmental stability of HCV and its susceptibility to chemical biocides. *J Infect Dis* **2010**; 201:1859–66.
25. Painsil E, He H, Peters C, Lindenbach BD, Heimer R. Survival of hepatitis C virus in syringes: implication for transmission among injection drug users. *J Infect Dis* **2010**; 202:984–90.
26. Pietschmann T, Kaul A, Koutsoudakis G, et al. Construction and characterization of infectious intragenotypic and intergenotypic hepatitis C virus chimeras. *Proc Natl Acad Sci U S A* **2006**; 103:7408–13.
27. Yanagi M, Purcell RH, Emerson SU, Bukh J. Hepatitis C virus: an infectious molecular clone of a second major genotype (2a) and lack of viability of intertypic 1a and 2a chimeras. *Virology* **1999**; 262:250–63.
28. Koutsoudakis G, Kaul A, Steinmann E, et al. Characterization of the early steps of hepatitis C virus infection by using luciferase reporter viruses. *J Virol* **2006**; 80:5308–20.
29. Sattar SA, Springthorpe VS, Adegbinrin O, Zafer AA, Busa M. A disc-based quantitative carrier test method to assess the virucidal activity of chemical germicides. *J Virol Methods* **2003**; 112:3–12.
30. Hahn JA, Page-Shafer K, Lum PJ, et al. Hepatitis C virus seroconversion among young injection drug users: relationships and risks. *J Infect Dis* **2002**; 186:1558–64.
31. Gottwein JM, Bukh J. Cutting the Gordian knot—development and biological relevance of hepatitis C virus cell culture systems. *Adv Virus Res* **2008**; 71:51–133.
32. Kamili S, Krawczynski K, McCaustland K, Li X, Alter MJ. Infectivity of hepatitis C virus in plasma after drying and storing at room temperature. *Infect Control Hosp Epidemiol* **2007**; 28:519–24.
33. Nascimbeni M, Mizukoshi E, Bosmann M, et al. Kinetics of CD4+ and CD8+ memory T-cell responses during hepatitis C virus rechallenge of previously recovered chimpanzees. *J Virol* **2003**; 77:4781–93.
34. Meyer MF, Lehmann M, Cornberg M, et al. Clearance of low levels of HCV viremia in the absence of a strong adaptive immune response. *Virol J* **2007**; 4:58.
35. Bond WW, Favero MS, Petersen NJ, Gravelle CR, Ebert JW, Maynard JE. Survival of hepatitis B virus after drying and storage for one week. *Lancet* **1981**; 1:550–1.
36. Edlin BR, Carden MR. Injection drug users: the overlooked core of the hepatitis C epidemic. *Clin Infect Dis* **2006**; 42:673–6.
37. Heimer R. Syringe exchange programs: lowering the transmission of syringe-borne diseases and beyond. *Public Health Rep* **1998**; 113(Suppl 1):67–74.
38. Gerberding JL. Management of occupational exposures to blood-borne viruses. *N Engl J Med* **1995**; 332:444–51.
39. Short LJ, Bell DM. Risk of occupational infection with blood-borne pathogens in operating and delivery room settings. *Am J Infect Control* **1993**; 21:343–50.
40. Rich JD, Taylor LE. The beginning of a new era in understanding hepatitis C virus prevention. *J Infect Dis* **2010**; 202:981–3.