19 patients with undetectable cccDNA upon long term anti-viral treatment

Randomization 1:2

6 patients continued treatment

13 patients stopped treatment

Follow up every 4-8 weeks

All 6 patients had undetectable HBV DNA and no ALT flare

All patients had HBV DNA rebound to >1000 IU/mL, (1st week 4 – 70 after treatment withdrawal)

12 patients were retreated when HBV DNA >2000 IU/mL

1 patient had HBV DNA below 2000 IU/mL.

had not been re-treated as of 150 weeks after treatment withdrawal

stopped treatment

Resumed treatment

HBV DNA (IU/mL)

0 10 20 30 40 50 60 70

weeks (from stopping treatment)

HBV DNA assay LLQD

Patient 1 · Patient 3
Patient 5 · Patient 6
Patient 7 · Patient 8
Patient 10 · Patient 11
Patient 13 · Patient 16
Patient 17 · Patient 19
Rebound of HBV DNA after cessation of nucleos/tide analogues in chronic hepatitis B patients with undetectable covalently closed circular DNA

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**Authors’ contributions**

CLL and DKHW contributed to the conception and design of the study. DKHW, and GTYW contributed to data collection. CLL, DKHW, WKS, and JF analyzed and interpreted the data. CLL and DKHW drafted the manuscript. WKS, JF and MFY critically revised the manuscript for important intellectual content. All authors approved the final version of the manuscript.
Abstract

Background and Aims: Nucleos/tide analogues (nucs) effectively suppresses serum hepatitis B virus (HBV) DNA. Previously, we have identified 21 patients with undetectable covalently closed circular DNA (cccDNA) upon long term nucs therapy. This study investigated the effect of nucleos/tide analogues (nucs) withdrawal in patients with undetectable cccDNA levels.

Methods: Nineteen patients on long term nucs (median 13.4 years) were recruited: 13 were randomized to discontinue nucs; six to continue taking nucs. All had undetectable cccDNA at the time of last liver biopsy (median time 2.9 years prior to randomization). Serum HBV DNA, hepatitis B surface antigen (HBsAg), hepatitis B core-related antigen (HBcrAg), liver biochemistry, and serum HBV RNA were monitored.

Results: At the time of randomization, all patients had undetectable serum HBV DNA and HBV RNA. Twelve of the 13 patients had HBV DNA rebound to 100 IU/mL within 20 weeks of nucs discontinuation. The thirteenth patient had HBV DNA rebound at week 70. Three patients experienced biochemical flares after re-treatment which subsequently resolved. There was no significant association between the time of HBV DNA rebound and baseline HBsAg, HBcrAg and alanine transaminase, duration of treatment, and age at which treatment was stopped (all p > 0.05). At the time of HBV DNA rebound, HBV DNA levels correlated with HBcrAg levels (p=0.003), but not with HBsAg levels (p=0.262).

Conclusions: In patients with undetectable intrahepatic cccDNA, virologic rebound still occurred after nuc cessation. At the rebound of HBV DNA, the kinetics of HBsAg production were independent of that of viral DNA replication. Additional studies are required to determine the factors that may predict virologic rebound and when nucs can be discontinued in HBsAg-positive CHB patients.
Lay Summary

In a previous study of 43 chronic hepatitis B (CHB) patients on prolonged nucleos/tide treatment (nucs) (median period 126 months), cccDNA was markedly reduced, with 21 of the liver biopsies having undetectable cccDNA. The present study randomized 19 of these patients to discontinue nucs (n=13) or to continue receiving treatment (n=6). All 13 patients who discontinued nucs has rebound of HBV DNA, 12 within 20 weeks of discontinuation and had HBV DNA rose to >2000 IU/mL, requiring resumption of treatment. Even in patients with undetectable cccDNA in liver biopsies, virologic relapse can still occur. Whether nucs can be discontinued in HBsAg-positive CHB patients remains to be investigated.
**Introduction**

Chronic hepatitis B (CHB) affects approximately 257 million people globally [1]. Following hepatocyte entry, the hepatitis B virus (HBV) relaxed circular DNA genome enters the nuclei, associates with cellular histones and other proteins and forms a covalently closed circular DNA (cccDNA) minichromosome. cccDNA is the template for HBV transcription and can only be measured in liver biopsies. Since nucleos/tide analogues (nucs) for the treatment of CHB have no direct action on cccDNA, the persistence of cccDNA is thought to be the main obstacle in achieving a “cure” for CHB [2]. However, it has been postulated that with prolonged nucs treatment, cccDNA may become depleted through natural cell division and cell death of the hepatocytes [3, 4]. In a previous study from our center of 43 patients on long-term nucs (median treatment duration 10.5 years) with three liver biopsies, there was a marked reduction of cccDNA by 99.89%, with 21 patients (49%) having undetectable cccDNA, as measured by a real-time PCR assay [3]. It is not known whether reduction of cccDNA to very low or undetectable levels is a sufficient endpoint for cessation of nucs treatment. The current study was designed to investigate the effect of withdrawal of nucs in patients with undetectable cccDNA levels.
Patients and Methods

In a previous study of patients undergoing long-term nuc treatment, we had recruited patients with 3 liver biopsies: baseline (before nuc treatment), 1 year after treatment, and ≥ 6 years after treatment [3]. cccDNA inside the liver tissues was measured by real-time PCR, as previously described [3, 5]. Briefly, total liver DNA extracted from liver tissues was subjected to digestion with plasmid-safe DNase (Epicenter, Wisconsin, MD), followed by “over-gap” real-time PCR amplification using primers spanning across the nicked regions of the HBV relaxed circular genome. Real-time PCR quantification was performed using the QuantiFast Probe PCR kit in a RotorGene Q real-time PCR system (Qiagen, GmbH, Hilden, Germany) with the “over-gap” primers and dual hybridization probes with fluorescence resonance energy transfer (FRET) technology, sequences of which have been described previously [5]. Serial diluted plasmids containing cloned HBV DNA was used as quantitation standards. Human genomic DNA content, which reflected the number of cells in the liver tissues, was measured by the Light-Cycler Control DNA kit (Roche Diagnostics, Branchburg, NJ). The lower limit of detection was 0.005 cccDNA copies/cell [3].

In the previous study, 21 patients with undetectable cccDNA were identified. Of them, 19 were recruited in the present study. Of the two remaining patients, one defaulted; the other was positive for HBV DNA at screening. Two of the 19 recruited patients were positive for the hepatitis B e antigen (HBeAg); 14 were positive for antibody against HBeAg (anti-HBe); and three were negative for both HBeAg and anti-HBe.

Computer-assisted randomization was performed to randomize the 19 patients to either discontinue nuc or continue nuc in the ratio of two to one. Thirteen patients were randomized to discontinue nuc, and 6 continue nuc.
After the discontinuation of nucs, all patients were seen every four to eight weeks to monitor serum HBV DNA by the COBAS HBV Test (Roche Molecular Diagnostics, Pleasanton, CA, USA; lower limit of detection 1 log IU/mL), hepatitis B surface antigen (HBsAg) titers by the Elecsys HBsAg II Quant Assay (Roche Diagnostics, Indianapolis, IN, USA; lower limit of detection 0.05 IU/mL), hepatitis B core-related antigen (HBcrAg) titers by the Lumipulse HBcrAg Assay (Fujirebio Inc, Tokyo, Japan; lower limit of detection 1 kU/mL), and liver biochemistry. Serum HBV RNA levels were measured using a rapid amplification of cDNA ends (RACE)-based real-time PCR method, with a lower limit of detection of 800 copies/mL, as previously described [6]. Rebound of HBV DNA was defined as having detectable serum HBV DNA of ≥100 IU/mL, which was equivalent to a ≥1 log increase from undetectable levels. Nucs were recommenced when HBV DNA levels further rose to ≥2000 IU/mL (3.3 log IU/mL). After resumption of nucs, patients were followed up every eight to sixteen weeks. The study was approved by the Institution Review Board of the University of Hong Kong and Hong Kong Hospital Authority West Cluster (Reference: UW 16-413) and was registered at The University of Hong Kong Clinical Trial Registry (Reference: HKUCTR-2110). Written consents were obtained from all patients recruited in this study.

Statistical analyses were performed by using IBM SPSS Statistics 25 (IBM, Armonk, NY, USA). Continuous variables were expressed as median and range. Related samples were tested with the Wilcoxon Sign Ranks Test. Correlation between two variables was tested using the Pearson correlation analysis. Statistical significance was defined by a p value of less than 0.05.
Results

Nineteen patients (13 male and 6 female; median age: 56 years [range 42 – 75]) with undetectable cccDNA were recruited in this study. Prior to randomization, of the 19 patients, 12 were taking ETV, 4 were taking telbivudine (LdT), 3 were taking tenofovir disoproxil fumarate (TDF). At the time of randomization, the median duration of treatment was 13.4 years (range: 8.7 – 14.9 years). The median duration between the last liver biopsy and randomization was 2.9 years (range: 2.5 – 3.2 years), during which all 19 patients had at least two measurements of HBV DNA and HBV RNA performed. All 19 patients had persistently undetectable serum HBV DNA and HBV RNA levels prior to randomization.

Thirteen patients (8 on ETV, 3 on LdT, and 2 on TDF) were randomized to stop nucs, of whom one was HBeAg-positive and 12 were HBeAg-negative. The median HBsAg and HBcrAg levels at the time of randomization was 414 IU/mL (range: 70 – 2780 IU/mL) and 2.6 kU/mL (range: <1 – 36.5 kU/mL), respectively. Four of 13 patients had undetectable HBcrAg at the time of randomization. After stopping nucs, all 13 patients had rebound of HBV DNA to >100 IU/mL, with a median time to rebound of 12 weeks (range: 4 – 70 weeks). Three patients had an early HBV DNA rebound at their first follow up at week 4: two were receiving TDF and one on LdT before stopping treatment. Three patients (one was on ETV and two on LdT) had HBV DNA rebound at week 8. The remaining 7 patients with HBV DNA rebound at weeks 12 – 70 (one patient at week 12, three patients at week 16, two patients at week 20, and one at week 70) were all receiving ETV before stopping treatment. There was no significant association between the time of HBV DNA rebound and baseline parameters such as baseline HBsAg and HBcrAg levels, baseline alanine transaminase (ALT), duration of nuc treatment, and age at which treatment was stopped (all p > 0.05).
The virologic and biochemical parameters at baseline and at the time of HBV DNA rebound of the 13 patients who stopped therapy were compared (Table 1). The median HBV DNA and HBcrAg level at the time of HBV DNA rebound was 3.16 log IU/mL and 5.80 kU/mL, respectively, both of which were significantly higher than that at the time of stopping nucs (p=0.001 and 0.005, respectively). Compared with baseline, there was no significant increase in HBsAg levels at the time of HBV DNA rebound. All 13 patients were asymptomatic, and their bilirubin and prothrombin time remained normal throughout the study. The six patients who continued to receive nucs had undetectable HBV DNA levels and normal ALT levels at last follow up.

The HBV DNA levels of the 12 patients with rebound before week 20 rose to >2000 IU/mL. They were treated either with the nucs they had been previously taking (for TDF and ETV patients) or with TDF (for LdT patients). The kinetics of virologic parameters and ALT levels after stopping of nucs (and resumption of nucs) are shown in Figures 1-3.

Three patients (Patients 6, 10, and 17) experienced elevations of ALT levels (≥ 2× upper limit of normal), all of whom had early HBV DNA rebound on or before week 8 (Figure 1). HBV DNA further increased to >2000 IU/mL within 2-4 weeks of HBV DNA rebound, leading to early resumption of nucs, after which HBV DNA returned to undetectable levels. In patients 6 and 10 (Figures 1A and 1B), HBV DNA rose to >5 log IU/mL after stopping nucs, followed by an increase in ALT to approximately 400 U/L. During HBV DNA/ALT flare, there was a slightly increase in HBsAg and HBcrAg, which were then decreased back to a low level after resumption of nucs. HBV RNA remained below the assay detection limit throughout the study in these two patients.

Patient 17 had a peak HBV DNA of 6.3 log IU/mL, following by a substantial ALT flare to 1764 U/L after the resumption of nuc (Figure 1C). This patient was positive for anti-
HBe at baseline. At the time of HBV DNA flare, there was a flare of all the other three markers measured (HBsAg, HBcrAg and HBV RNA), which were then decreased to a low/undetectable level after HBV DNA/ALT flare. An extended follow-up in this patient showed that this patient became HBsAg-negative at week 64 after stopping of nucs, which was equivalent to 48 weeks after re-treatment with TDF (data not shown).

Nine patients had HBV DNA rebound to >2,000 IU/mL but without ALT flare (Figure 2). Three of them (Patients 3, 5 and 13; Figure 2A) had early HBV DNA rebound on or before week 8, while six patients (Figure 2B) had HBV DNA rebound between weeks 12-20. By week 22, all nine patients resumed nuc treatment. In general, there was a slight (< 1 log) increase of HBcrAg around the time of HBV DNA rebound, and HBsAg levels did not seem to correlate with HBV DNA flare. HBV RNA was mostly below the assay detection limit in all patients except Patient 5. In Patient 5, who was HBeAg-positive at the time of randomization, there was an approximately 2 log increase in HBcrAg and a more than 3 log increase in HBV RNA around the time of HBV DNA flare, at which ALT peaked at only 39 U/L. HBcrAg and HBV RNA returned to level comparable to baseline after resumption of nucs.

The thirteenth patient (Patient 14) had a late HBV DNA rebound to >100 IU/mL at week 70 (Figure 3). HBV DNA levels remained below 2000 IU/mL during all follow-up visits of eight to sixteen weeks apart, with the latest follow-up being 150 weeks. This patient had undetectable HBcrAg but with HBsAg of 2780 IU/mL at baseline. HBV DNA peaked at week 126 at 1200 IU/mL. Thus antiviral treatment had not been resumed in this patient. The peak ALT was 76 U/mL at week 44, and HBcrAg and HBV RNA levels were below or near the assay detection limit during follow-up. Interestingly, this patient had a high level of HBsAg (>3 log IU/mL) throughout the study. Figure 4 shows the correlation between the levels of HBcrAg and HBsAg with HBV DNA levels at the time of HBV DNA rebound.
HBcrAg showed good correlation with HBV DNA levels (p=0.003) but there was no correlation between HBsAg and HBV DNA levels (p=0.262).
Discussion

Recently there is a debate as to whether nuc therapy can be stopped when there is substantial evidence of viral inactivity in CHB patients [7-12]. Several viral markers, such as HBsAg, HBcrAg, and HBV RNA, have been suggested as markers of viral inactivity [13-17].

This is the first study to investigate the withdrawal of nuc in patients with undetectable cccDNA in their hepatocytes. All 13 patients randomized to stop therapy had HBV DNA rebound. Six patients had rapid elevation of HBV DNA levels 4 – 8 weeks after cessation of therapy, seven had HBV DNA rebound to > 100 IU/mL at 12 – 20 weeks, and one had a late rebound at week 70. Compared with patients receiving ETV, patients receiving TDF or LdT seemed to have earlier HBV relapse. This is consistent with the findings of another study which shows that patients with TDF withdrawal have earlier HBV rebound [18]. The biochemical flares were independent of the baseline HBeAg status, with the most severe flare of ALT (1764 U/L) occurring in a patient who was anti-HBe positive at baseline. In the single HBeAg-positive patient who stopped treatment the highest ALT was 39 U/L only.

The rebound of HBV DNA after stopping nucs suggests that even small amount of cccDNA, not detectable by our assay, can still allow viral replication causing HBV DNA rebound. Nine out of 13 patients who stopped nucs still had detectable HBcrAg, a marker of cccDNA transcription activity. This signifies that HBV replication still occurred in these “cccDNA-negative” patients. In fact, except for the few patients with very low or undetectable HBcrAg throughout the study (patients 3, 8 and 14), HBcrAg profile mirrored that of HBV DNA. In addition, HBcrAg showed good correlation with HBV DNA at the time of HBV DNA rebound. While serum HBV RNA may also be a useful marker of HBV transcription activity, the majority of patients had undetectable serum HBV RNA. It is
possible that, in patients with long-term nucs, the cccDNA pool may become very small, resulting in a serum HBV RNA level too low to be detected. Therefore, in patients with long term nucs, HBcrAg may be useful to define HBV intrahepatic replicative activity, as demonstrated in previous studies [19, 20], while the usefulness of serum HBV RNA requires further studies with more sensitive assays.

There was no correlation of HBV DNA rebound with HBsAg levels. This is probably due to the expression of HBsAg from integrated HBV DNA and presence of excess free circulating HBsAg particles. HBsAg seroclearance occurs only in a small proportion of patients, some of whom may have hepatic flare prior to HBsAg seroclearance [21-23]. However, whether such beneficial hepatic flare is predictable and whether it outweighs the risk of uncontrolled flare are still controversial [7, 8, 23-25]. In the present study, we restarted treatment independent of the ALT levels. We therefore did not investigate the possibility of beneficial flares. The present study was designed to avoid severe reactivation.

In the three patients who experienced severe ALT flares (400 – 1760 U/L), the flares were observed after re-treatment. It was not known whether the flare would be more severe if the re-treatment was further delayed. The patient with ALT flare of 1760 U/L had HBsAg seroclearance 48 weeks after re-treatment with TDF, suggesting that beneficial flares leading to HBsAg seroclearance could still occur after resumption of nucs. The timing of nucs resumption, as well as the identification of factors predicting HBsAg seroclearance at nucs withdrawal, requires further investigations.

The limitation of this study is the small number of patients involved. However this is unavoidable since repeated liver biopsies were required to document the levels of cccDNA in patients on prolonged nucs treatment. Our study is the only study to date to recruit patients with documented undetectable cccDNA levels. Another limitation concerns the sensitivity of the assays used for cccDNA and serum HBV RNA detection. To date, standardized assays for
cccDNA and HBV RNA are not available. The early rebound of HBV DNA in this study might be due to small amounts of cccDNA not detectable by the current assay, or to liver biopsy sampling errors. Further studies should be performed with the development of a more sensitive cccDNA and HBV RNA assays, such as digital droplet PCR-based assays for cccDNA [26].

In conclusion, this study showed that absence of detectable cccDNA in liver biopsies does not preclude the occurrence of virologic rebound, and patients with undetectable cccDNA still harbor detectable virologic markers in the serum. Additional studies are required to determine whether the absence of cccDNA, in combination with measurement of other parameters, can help prevent uncontrolled hepatic flare and predict HBsAg seroclearance.
References


**Figure legends**

**Figure 1.** Virological and biochemical parameters of the three patients who experienced ALT flare of ≥2 × ULN after stopping of treatment. A. Profile of patient 6; B. Profile of patient 10; and C. Profile of patient 17. Thick arrows denote the time of resumption of nucs.

**Figure 2.** Virological and biochemical parameters of the nine patients who did not have ALT flare. Thick arrows denote the time of resumption of nucs. A. Patients with early HBV DNA rebound on or before week 8. B. Patients with late HBV DNA rebound between weeks 12 – 20.

**Figure 3.** Virological and biochemical parameters of the patient whose HBV DNA remained below 2000 IU/mL and hence did not resume nuc.

**Figure 4.** Correlation between levels of HBV DNA levels at the time of HBV DNA rebound with (A) hepatitis B core-related antigen (HBcrAg); level of significance: p = 0.003 (Pearson Correlation Test) and (B) hepatitis B surface antigen (HBsAg); level of significance: p = 0.262 (Pearson Correlation Test).
Table 1. Comparison of virologic and biochemical parameters at baseline and at the time of HBV DNA rebound using the Wilcoxon Signed Ranks Test.

<table>
<thead>
<tr>
<th>Parameter*</th>
<th>At baseline</th>
<th>At time of HBV DNA rebound (4–70 weeks)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBV DNA, log IU/mL</td>
<td>&lt;1</td>
<td>3.16 (2.16–5.76)</td>
<td>0.001</td>
</tr>
<tr>
<td>HBsAg, log IU/mL</td>
<td>2.62 (1.84–3.44)</td>
<td>2.48 (1.95–3.26)</td>
<td>0.507</td>
</tr>
<tr>
<td>HBcrAg, kU/mL</td>
<td>2.60 (&lt;1–36.5)</td>
<td>5.80 (&lt;1–143.3)</td>
<td>0.005</td>
</tr>
<tr>
<td>ALT levels, U/L</td>
<td>27 (18–62)</td>
<td>29 (16–54)</td>
<td>0.726</td>
</tr>
</tbody>
</table>

* values expressed as median (range)
**Highlights**

- Chronic hepatitis B patients on long term nucleos/tide analogue treatment with undetectable HBV DNA, may also have undetectable covalently closed circular DNA (cccDNA) in their liver biopsies.
- Stopping treatment for patients with undetectable cccDNA resulted in rebound of serum HBV DNA, mostly within 20 weeks, requiring re-treatment when HBV DNA reached 2000 IU/mL or above.
- There is no association between time of HBV DNA rebound and other viral markers, including HBsAg titers, HBcrAg and transaminase levels, and age.
- Even in patients with undetectable cccDNA in liver biopsies by current assays, virologic relapse can still occur.