Cost-effectiveness of sofosbuvir for the treatment of chronic hepatitis C-infected patients

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SUMMARY. The efficacy of treatment for hepatitis C genotype 1 infection has significantly improved with the introduction of first-generation protease inhibitors. However, there remains a need for effective treatments for patients infected with other genotypes, for nonresponders and patients unsuitable for interferon. Sofosbuvir is the first nucleotide polymerase inhibitor with pan-genotypic activity. Sofosbuvir-based regimens have resulted in >90% sustained virological response across treatment-naïve genotype 1–6 patients in five phase III clinical trials of sofosbuvir administered with ribavirin or pegylated interferon and ribavirin. This analysis evaluates the cost-effectiveness of sofosbuvir within the current licensed indication, for genotype 1–6 in the UK. A Markov model followed a cohort of 10 000 patients over lifetime, with approximately 20% initiating treatment for compensated cirrhosis. Sofosbuvir-regimens were compared to telaprevir, boceprevir, pegylated interferon and ribavirin, or no treatment. Costs and outcomes were discounted at 3.5%. The cost perspective utilized costs applicable to the National Health Service in the UK. Sofosbuvir proved to be cost-effective in most patient populations with incremental cost-effectiveness ratios (ICERs) at £11 836/QALY and £7292/QALY against telaprevir and boceprevir, respectively. In genotype 3, sofosbuvir had a weighted ICER of £18 761/QALY. Sofosbuvir-based regimens are a cost-effective option for the majority of hepatitis C-infected patients in the United Kingdom although the incremental cost-effectiveness varies by genotype and regimen. Sofosbuvir and ribavirin is an alternative regimen for patients unsuitable for interferon.

Keywords: chronic hepatitis C infection, cost-effectiveness analysis, sofosbuvir.

INTRODUCTION

Chronic hepatitis C (CHC) caused by the hepatitis C virus (HCV) is associated with significant hepatic and extra-hepatic morbidity and a significant societal health economic burden. Approximately 75–85% of patients progress to develop CHC, which is largely asymptomatic in the early stages of chronic disease. CHC patients are at a greater risk of developing cirrhosis, end stage liver disease or hepatocellular carcinoma (HCC). Over a period of 20 years, it is estimated that 10–15% of CHC patients eventually develop cirrhosis. Of these, an estimated 1–4% of patients develop HCC [1].

In the UK, it is estimated that approximately 215 000 individuals are chronically infected with HCV [2]. Although, the incidence of HCV infection in the UK is declining, due to the lag time between the infection and disease, the future disease burden attributable to HCV remains considerable. It is estimated that if left untreated, 15 840 individuals in England alone will be living with cirrhosis or HCC by 2020, with more than 4200 requiring a liver transplant (LT) [2]. A recent study showed that the economic burden from CHC in patients achieving a sustained virological response (SVR) following antiviral therapy is substantially lower than in nonresponders (£190 vs...
Sofosbuvir (SOF) is the first nucleotide polymerase inhibitor with pan-genotypic activity and a high barrier to resistance without drug-to-drug interactions that would enable a broader population of patients the possibility of cure. This study estimated costs derived from the UK National Health Service (NHS) payer perspective for genotype (GT) 1 patients treated with pegylated interferon and ribavirin (PEG-INF + RBV) [3].

Seven genotypes and several subtypes of HCV have been identified. In England, the most common genotypes of HCV are GT1 and GT3, accounting for nearly 90% of all HCV infections [2].

The nature and duration of INF-treatment varies according to GT, stage of disease and prior response. In the UK, current treatment options include dual therapy (PEG-INF + RBV) and triple therapy (protease inhibitor ((PI); telaprevir or boceprevir in combination with PEG-INF + RBV). Dual therapy is the standard of care (SOC) for GTs 2 and 3 and triple therapy for GT1 [4–6].

Triple therapy has improved SVR rates for treatment-naïve (TN) or treatment-experienced (TE) GT1 patients. However, treatment remains suboptimal for many patients, and INF is unsuitable for patients contraindicated or intolerant to INF therapy [7]. Treatment efficacy is also influenced by the presence of cirrhosis and patient’s prior treatment status. It is estimated that of all diagnosed HCV patients, approximately 20% actually commence treatment and only 3–4% of the total diagnosed population achieves SVR [8]. Current therapies are also associated with a range of limitations including long and complex treatment regimens, severe side-effects that have led to treatment discontinuations in real-world settings (>20–30%), and the development of treatment-resistant viral mutations, all of which can lead to treatment failure [9].

Thus, there is a clear medical need for more effective pan-genotypic regimens with a high barrier to resistance without drug-to-drug interactions that would enable a broader population of patients the possibility of cure.

MATERIALS AND METHODS

Model structure

A Markov state-transition model (Fig. 1) was developed to represent the natural history of CHC, based on published transitional probabilities and recent economic models [6,12–14]. The model structure was adapted to reflect the pivotal phase III trials that randomized patients based on cirrhotic and noncirrhotic status, as assessed by FibroScan® (Echosens, France) and Fibrotest® (BioPredictive, Paris, France). No liver biopsy was performed at study entry, and therefore, liver fibrosis data according to the METAVIR score were not available. Trial results were provided for the entire cohort as well as for the noncirrhotic and cirrhotic cohorts.

Patients entering the model in the noncirrhotic (NC) (METAVIR F0-F3) or cirrhotic (METAVIR F4) health states (HSs) were treated with antiviral therapy, and those who achieved SVR at 12 or 24 weeks post-treatment (SVR at 12 weeks has been established as an appropriate endpoint for regulatory approval [15]) were assumed to enter the ‘SVR’ HS and considered to be cured. The risk of HCC development is considered to be reduced in patients attaining SVR but is not eliminated. This assumption is tested in the sensitivity analysis (SA); recurrence and re-infection of HCV are considered for both NC and cirrhotic patients by allowing them to transition to their initial HS. Patients not achieving SVR can progress to more advanced stages of the disease: DCC, HCC or LT. The probability of requiring a LT on developing HCC was also explored in the SA.

Although not shown in the model diagram, age-specific general population mortality rates were applied to each HS. In addition, disease-specific mortality was also assumed for patients in advanced stages of the disease.

The analysis considered a lifetime horizon (100 years of age). The cycle length was 3 months for the first 2 years, to correctly assign treatment costs and utilities as SOF is given for either 12 or 24 weeks and allow patients to progress to the cured or more advanced health states when SVR-12 is assessed, that is, at 24 and 36 weeks. Cycle length was considered yearly thereafter. A half-cycle correction was implemented to account for longer cycle lengths following the first 2 years. The model was based on the UK NHS and the Personal Social Services perspective including only direct healthcare costs. Costs and outcomes were discounted at 3.5% [16].

Model population

Baseline demographic characteristics (i.e. cirrhosis stage, age, weight) were obtained from a UK registry, the HCV research UK database, that studies a cohort of up to 10 000 HCV-infected patients from the major liver centres in the UK [17]. Patients started treatment at age 40 or
45 years across genotypes and approximately 20% of the patients initiated treatment at the compensated cirrhosis (CC) stage [17].

Efficacy data for the analysis were based on five phase III randomized controlled trials (RCTs) for SOF: NEUTRINO, FISSION, POSITRON, FUSION, VALENCE and five phase II RCTs: QUANTUM, SPARE, ELECTRON, PROTON and LONESTAR-2 [10].

Model inputs

Treatment strategies
The intervention and comparator treatment strategies were defined based on the marketing authorizations and licensed doses for the respective patient population [10,18].

Efficacy: SVR rates
The SVR rate of SOF for each patient group was obtained from the corresponding pivotal trials of SOF. The SVR rate of each comparator was derived from SOF trials where possible; in the absence of data, a conservative approach was taken using the estimates from previous UK health technology assessments (HTA) or selected where bias in the data was in favour of the comparator regimens based on published trials.

Transition probabilities
Transition probabilities (TPs) for the analyses were taken from the latest UK HTAs [12,13]. TPs from NC to CC HS were estimated based on data available in the literature [19]. As the TPs were reported separately for mild to moderate and moderate to CC, age-specific TPs were estimated by converting these to a two-state Markov model (NC to CC) (see supporting information). Annual mortality rates, by age group, were obtained from the Office of National Statistics [20].

Health-related quality of life
The HS utilities and utility decrements for the comparators were obtained from the literature [5,6,21]. The utility decrements for SOF were obtained from the respective phase III RCTs [22]. As SF-36 was used to measure the quality of life data in the SOF trials, these estimates were mapped to SF-6D and EQ-5D using published algorithms [23,24]. SF-6D values were used in the base case analysis. In the deterministic sensitivity analysis (DSA), the ranges for the utility decrements for SOF were adjusted to include EQ-5D.

Resource use and Costs
Drug costs for all treatments were obtained from the British National Formulary (BNF) [25].

Unit costs associated with adverse events (AEs) were estimated based on costs reported in the BNF, National Schedule of Reference Costs and the Personal Social Services Unit (PSSRU) [25–27]. The associated resource use was obtained from consultations with clinical experts and the literature [6,25,28].

The cost of monitoring patients treated with either SOF or the comparator strategy was based on a microcosting approach. The unit costs and resource use were based on clinical opinion or estimates from the literature [12,21,26,29].

Costs associated with each HS post-treatment were obtained from the literature. The costs associated with the mild and moderate CHC HS were used to estimate the cost of the NC HS, assuming a 77/23 split between mild and moderate from patient distribution in the SOF trials. The costs chosen for model inputs were all used by previous HTAs [12,13] (see supporting information).

Where necessary, costs were inflated to 2011–2012 prices based on the Hospital and community health services index published by the PSSRU [27].

Model outcomes
Model outcomes included the number of cases of CC, DCC, HCC and LT avoided, number of life years (LYs) and quality-adjusted life years (QALYs) gained. Economic outcomes included treatment and total costs and the incremental cost-effectiveness ratio (ICER).

Sensitivity analyses
To assess the uncertainty in the results, DSA and probabilistic sensitivity analysis (PSA) were conducted. The following inputs were varied in the DSA: treatment costs, HS costs, utility weights, TPs, discount rates, the probability of death for the general population, percentage of cirrhotic patients, SVR rates, HS costs, HS utilities, treatment-related utility decrements, utility increment post-SVR and incidence of AEs. These parameters were varied based on the
95% confidence intervals reported in the literature and SOF RCTs [12,30–34].

In PSA, HS utilities, treatment-related utility decrements, the increment after reaching SVR, treatment and HS costs, TPs and SVR rates were varied.

RESULTS

Base case analysis

Overall, sofosbuvir-based regimens offer a favourable cost-effectiveness profile compared with current standard of care for genotypes 1–6. Sofosbuvir-based regimens were also associated with significant improvements in health outcomes and long-term complications across all genotypes (Tables 1 and 2).

In treatment-naïve interferon eligible GT1 patients, 12-week SOF + PEG-INF2a + RBV was cost-effective, at a £20 000/QALY threshold, when compared to treatment with protease inhibitors or PEG-INF + RBV. The ICER for 24-week SOF + RBV vs no treatment (NT) was higher among treatment-naïve unsuitable for interferon GT1 patients (£49 249/QALY) and did not fall within the cost-effectiveness threshold accepted by NICE.

The analysis also showed that 12-week SOF + RBV is cost-effective compared to standard of care in treatment-naïve/treatment-experienced unsuitable for interferon and treatment-experienced interferon eligible GT2 patients at a £20 000/QALY threshold. However, this was not the case in treatment-naïve interferon eligible GT2 patients when compared to 24-week PEG-INF2a + RBV (£46 324/QALY).

At a threshold of £20 000/QALY, the 12-week SOF + PEG-INF2a + RBV regimen is also cost-effective compared to no treatment or 48-week PEG-INF2a + RBV in treatment-experienced interferon eligible GT3 patients. The regimen is cost-effective at a £30 000/QALY threshold when compared to no treatment for treatment-naïve/treatment-experienced unsuitable for interferon and compared to 24-week PEG-INF2a + RBV in treatment-naïve interferon eligible GT3 patients.

In GT4/5/6 treatment-naïve interferon eligible patients, 12-week SOF + PEG-INF2a + RBV was shown to be cost-effective at a £30 000 threshold compared to 48-week PEG-INF2a + RBV. This is a conservative estimate as the

Table 1 Summary of results – ICER

| Strategy by indication | ICER per QALY | ICER per LY |
|------------------------|---------------|-------------|
| GT1 TN IE              |               |             |
| SOF+PEG-INF2a+RBV(12 weeks) vs Telaprevir+PEG-INF2a+RBV | £11 836 | £17 466 |
| SOF+PEG-INF2a+RBV(12 weeks) vs Boceprevir+PEG-INF2b+RBV | £7292 | £10 911 |
| SOF+PEG-INF2a+RBV(12 weeks) vs PEG-INF2a+RBV(48 weeks) | £14 930 | £21 770 |
| GT1 TN UI              |               |             |
| SOF+RBV(24 weeks) vs NT | £49 249 | £78 620 |
| GT2 TN IE              |               |             |
| SOF+RBV(12 weeks) vs PEG-INF2a+RBV(24 weeks) | £46 324 | £61 216 |
| GT2 TN UI              |               |             |
| SOF+RBV(12 weeks) vs NT | £8154 | £11 242 |
| GT2 TE IE              |               |             |
| SOF+RBV(12 weeks) vs PEG-INF2a+RBV(48 weeks) | £14 185 | £25 384 |
| SOF+RBV(12 weeks) vs NT | £10 126 | £14 999 |
| GT2 TE UI              |               |             |
| SOF+RBV(12 weeks) vs NT | £8591 | £11 895 |
| GT3 TN IE              |               |             |
| SOF+PEG-INF2a+RBV(12 weeks) vs PEG-INF2a+RBV(24 weeks) | £20 613 | £21 375 |
| GT3 TN UI              |               |             |
| SOF+RBV(24 weeks) vs NT | £21 478 | £26 510 |
| GT3 TE IE              |               |             |
| SOF+PEG-INF2a+RBV(12 weeks) vs NT | £8557 | £10 608 |
| SOF+PEG-INF2a+RBV(12 weeks) vs PEG-INF2a+RBV(48 weeks) | £12 246 | £17 027 |
| GT3 TE UI              |               |             |
| SOF+RBV(24 weeks) vs NT | £28 569 | £38 763 |
| GT4/5/6 TN             |               |             |
| SOF+PEG-INF2a+RBV(12 weeks) vs PEG-INF2a+RBV(48 weeks) | £26 797 | £72 297 |

ICER, Incremental cost effectiveness ratio; IE, Interferon eligible; LYs, Life years; NT, No treatment; PEG-INF, Pegylated interferon; QALYs, Quality-adjusted life years; RBV, Ribavirin; SOF, Sofosbuvir; TE, Treatment-experienced; TN, Treatment-naïve; UI, Unsuitable for interferon.
SVRs for cirrhotic patients with these genotypes (50%) treated with the sofosbuvir-regimen were based on small patient numbers. Nevertheless, the sofosbuvir-based regimen was associated with substantially superior clinical outcomes compared to PEG-INF + RBV.

**Sensitivity analysis**

The DSA showed that the base case ICERs were sensitive to the discount rates applied to both costs and outcomes and the utility increments following SVR. For the treatment-naïve interferon eligible GT1/2 patient populations, the results were also sensitive to changes in the SVR rate for cirrhotic patients or the comparator treatment.

The probability of sofosbuvir being cost-effective at a willingness-to-pay threshold of £20 000/QALY is illustrated in Fig. 2:

- In GT1 interferon eligible patients it was over 80%. For patients unsuitable for interferon the probability fell below 5%.
- In GT2 patients, it was above 90% across all indications and comparators except against PEG-INF + RBV where the probability was <5% and approximately 80% among the treatment-naïve interferon eligible and treatment-experienced interferon eligible, respectively.
- In GT3 patients, it was over 89% for treatment-experienced interferon eligible patients and lower than 50% for those who were treatment-naïve interferon eligible/unsuitable for interferon and treatment-experienced unsuitable for interferon.
- In GT4/5/6 TN patients, the probability was approximately 30%.

**DISCUSSION**

The current PI-based treatment regimens for HCV have significantly improved SVR rates for GT1 patients. However, there remains a significant need for new better tolerated and more effective pan-genotypic regimens for both TN and TE patients, with CC or DCC. Significant need exists.

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**Table 2 Summary of results – Health outcomes**

| Strategy by indication | Difference Lives LT HCC CC DCC Costs |
|------------------------|-------------------------------------|
| GT1 TN IE              | −32 −56 −168 −393 −398 £5288       |
| GT1 TN IE              | −100 −160 −484 −1133 −1649 £63 903 |
| GT2 TN IE              | −43 −79 −229 −534 −542 £27 779   |
| GT2 TN IE              | −203 −337 −1012 −2367 −3016 £20 051|
| GT3 TN IE              | −103 −164 −499 −1172 −1770 £19 088|
| GT3 TN IE              | −181 −293 −882 −2066 −2913 £22 339|
| GT3 TN IE              | −199 −330 −990 −2315 −2969 £20 697|
| GT4/5/6 TN             | −96 −185 −531 −1234 −864 £24 970 |
| GT4/5/6 TN             | −218 −373 −1107 −2585 −2793 £55 137|
| GT4/5/6 TN             | −195 −334 −992 −2315 −2485 £19 634|
| GT4/5/6 TN             | −111 −190 −569 −1330 −1428 £16 843|
| GT4/5/6 TN             | −172 −285 −851 −1990 −2538 £58 828|

CC, Compensated cirrhosis; DCC, Decompensated cirrhosis; GT, Genotype; HCC, Hepatocellular carcinoma; IE, Interferon eligible; LT, Liver transplant; NT, No treatment; PEG-INF, Pegylated interferon; RBV, Ribavirin; SOF, Sofosbuvir; TE, Treatment-experienced; TN, Treatment-naïve; UI, Unsuitable for interferon.
for patients with DCC in whom INF is unsuitable. Phase III trials have shown SVR rates of more than 90% across all genotypes with only 12 weeks of SOF + PEG-INF + RBV in TN patients [10]. Furthermore, the INF-free SOF regimen represents a major breakthrough in the treatment of HCV in UI patients who previously had no effective treatment alternatives [35].

With the exception of TN IE GT2 (SOF + RBV (12 weeks) vs PEG-INF2a + RBV (24 weeks)) and TN UI GT1 patients (SOF + RBV (24 weeks) vs NT), our analysis shows that SOF-based regimens have a favourable cost-effectiveness profile compared to SOC for GT1-6, and ICERs are within the current willingness-to-pay thresholds accepted by NICE. It is worth noting that the prevalence of GT2 HCV infection in the UK is low (6%), and that the INF-free SOF regimen is a novel therapeutic option for a relatively small proportion of the UK HCV patient population [2,10,36]. The 24-week regimen of SOF + RBV for GT3 TN/TEUI showed ICERS > £20 000/QALY.

Although our analysis primarily focused on mono-infected HCV patients, it is worth noting that the SVR rates for the HIV co-infected population are similar to mono-infected patients across genotypes. Furthermore, the recent EASL recommendations on treatments for HCV highlight that HCV treatment in HCV/HIV co-infected persons are identical to those with HCV mono-infection [35]. As co-infected patients are likely to progress faster, ICERs are expected to be lower than those estimated for the mono-infected population (Fig. 3).

Our analysis has several strengths. The model structure developed for this analysis was similar to previous economic models and presents the natural course of the disease [6,12–14]. The structure was adapted to be consistent with the study design of the pivotal phase III RCTs of SOF that randomized patients based on whether they were NC or cirrhotic, as assessed by FibroScan® and Fibrotest®. Studies that evaluated the efficacy of FibroScan® and Fibrotest® have shown that both technologies work very well for staging patients with no or minimal fibrosis as well as patients with advanced fibrosis or cirrhosis [37]. However, when used to evaluate patients with moderate disease (e.g. METAVIR stage F2), these tests are not as accurate as a liver biopsy.

To ensure the model was representative of the UK patient population, the demographic characteristics for all
the genotypes were obtained from a UK registry [17]. Furthermore, we conducted extensive SAs and externally validated the results using recent NICE submissions that utilized similar model structures reflective of UK clinical practice.

This study has several caveats. Our analysis has only examined the efficacy of SOF in GT1 TN patients. Although SOF is indicated for use in prior INF nonresponders, we did not assess the cost-effectiveness of SOF in TE GT1 patients due to the lack of phase III RCTs.

Limited data were available in the literature to populate comparator SVRs in the model for the ‘NC’ and ‘cirrhotic’ HSs, in particular for the TE GT2/3 patients. This in part may be explained by the high unmet need and the fact that many clinicians have not retreated this population unless there is an urgent need. In most instances, cirrhotic and NC SVR rates were based on the same definitions as those used in the SOF trials, that is METAVIR F0-F3 and METAVIR F4, respectively. However, in the absence of comparator data, we considered SVR rates of the F0-F2 patients for the NC and those of F3-F4 patients for the cirrhotic. For TE GT2/3 patients, SVRs were assumed to be the same regardless of whether the patients were NC or cirrhotic (due to the lack of relevant clinical evidence). These conservative approaches are likely to favour the comparator rather than SOF. Secondly, the analysis did not account for potential drug wastage for PEG-INF, a conservative approach given the pharmacological costs of the comparator regimens in the analysis was assumed to be lower. Finally, the model did not account for the potential reduction in transmission of HCV infections following successful treatment of the infection. However, as SOF was associated with higher SVRs compared to the current SOC across the genotypes, the benefits associated with reduced economic and health burden would also be higher for the SOF-based regimens.

To conclude, 12-week SOF-based regimens are a cost-effective alternative to the current SOC for HCV. SOF offers a novel alternative for patients with HCV, making successful HCV cure a realistic probability for a significant proportion of patients who would not have been eligible for, or able to tolerate, current INF-based regimens.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1: SVR by indication.
Table S2: Transition probabilities.
Table S3: Quality of life mono-infected.
Table S4: Treatment unit costs.
Table S5: Adverse event drug unit costs.
Table S6: Adverse event treatment dosing and duration.
Table S7: Other adverse event costs.
Table S8: Monitoring unit costs.
Table S9: Health state costs.

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