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Title

A mixed-methods evaluation of point-of-care hepatitis c virus RNA testing in a Scottish prison.

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Abstract

Objectives

Hepatitis C Virus (HCV) poses a global public health threat. Prisons are a focus of prevention efforts due to high infection burdens. Expedition of treatment for incarcerated people is critical, as many are short-term sentenced. We evaluated point-of-care (PoC) HCV RNA testing in a maximum-security Scottish prison and assessed its impact on transition to treatment. We also evaluated costs and determinants of implementation.

Design

Mixed-methods evaluation of a single-centre care pathway pilot using NHS service data from 2018-21. Descriptive statistics and survival analysis were undertaken. Cost analysis was assessed from a provider perspective. Healthcare staff participated in semi-structured interviews and thematic analysis with a deductive approach was undertaken to identify implementation determinants.

Setting

A large maximum-security Scottish prison health centre administered by the NHS.

Participants

296 incarcerated NHS patients (all male) and six NHS staff members (two male, four female).

Interventions

Hepatitis C Virus (HCV) testing using the Cepheid GeneXpert platform with Xpert® HCV VL Fingerstick assay.

Outcome measures

The main outcome was survival (in days) from HCV test to treatment initiation. Secondary outcomes were cost-per-cure obtained and determinants of implementation.

Results

During the pilot, 167 Xpert® tests were administered, with an 84% success rate, and treatment transition was superior for those who received it (*p*=.014). Where PoC tests were administered, shorter survival to treatment was observed (19 vs 33 days: *a*HR 1.91 [1.03-3.55], *p*=.040; 19 vs 50 days; *a*HR 3.76 [1.67-8.46], *p*=.001). PoC was costlier than conventional testing but sensitive to multiple factors. In qualitative analysis, 70 determinants were identified.

Conclusions

Integrating PoC HCV RNA diagnosis into nurse-led HCV care in a maximum-security prison health centre shortens survival to HCV treatment. However, there are cost implications to this approach and multiple determinants that impact upon implementation should be addressed.

Strengths and Limitations of this study

- The study is strengthened by assessing the feasibility of point-of-care (PoC) testing from multiple angles which address clinical impact, costs to the health service, and barriers and facilitators to implementation, giving a holistic view of this approach.
- In contrast to other similar work, a strength of this study is that PoC testing was administered by nurses in the prison health centre.
- The study is limited by a small sample in the qualitative component, and its single-centre nature, which restricts the generalisability of the findings.
- The study is further limited by only including NHS staff in the qualitative component, which was due to the nature of the approvals obtained.

Introduction

Hepatitis C Virus (HCV) infection is an enduring global public health threat. For those infected, in the absence of diagnosis and linkage to treatment, it can cause long-term negative health outcomes. Prisons have been an important focus of HCV prevention efforts due to their high HCV burden relative to the general population, which intersects with the large number of people who inject drugs (PWID) who are imprisoned.[1] Imprisonment rates among PWID are substantial, with up to 58% estimated to have ever been incarcerated.[2] Further figures suggest that up to 38% of incarcerated persons may have been exposed to HCV, due to the overlapping nature of injection drug use (IDU) and incarceration, and the absence of primary prevention for PWID whilst incarcerated.[3,4] Sharing of non-sterile injecting equipment in prisons is the leading cause of HCV transmission.[2] A previous study of Scottish prisons found that 32% of people in prison had a history of IDU and, among those, HCV prevalence was 53%.[5]

Recent data indicate that approximately 71% of individuals test positive for illicit substances upon reception to Scottish prisons; of those, 29% test positive for opioids and 24% for cocaine, which are commonly injected.[6] In the prison in this evaluation, approximately 38% and 18% of individuals tested positive for these respectively upon reception, implying an ongoing risk of blood-borne virus (BBV) transmission.[6] The Scottish justice system has a 'remand problem', defined as imprisonment awaiting sentence for 40-140 days. [7,8] In recent data, which spans the pilot period of this project, those identified as being in the part-year prison population across the prison estate, i.e. residing in a given establishment for less than one whole year, was estimated at 80.2%.[9] Recent figures for HMP Perth, the prison in this pilot, estimated the remand population at approximately 22.8%.[10] These figures suggest substantial proportions of the prison population are highly transient, at risk of HCV transmission, with a short time-frame for healthcare engagement.

In the context of HCV, expedition of treatment for incarcerated persons is important to avoid loss to the system. Treating HCV-infected individuals whilst incarcerated has been identified

as an important engagement strategy for people otherwise disconnected from conventional healthcare.[11] HCV treatment duration is relatively fixed, which leaves diagnosis – in the absence of enhanced harm reduction supports to reduce risk, by enhancing primary prevention efforts, which are scarcely available in prisons – the key remaining modifiable care component.[12,13] This is especially pertinent to Tayside because Dundee, whose population is served by the prison in this evaluation, has the highest rate of incarceration per head of population in Scotland, as well as a historically high burden of HCV infection.[9,14]

In recent years, point-of-care (PoC) HCV testing platforms have become available which could ameliorate time burdens associated with existing testing methods and streamline linkage to treatment. However, the evidence documenting the impact these devices have in real-world prison contexts is nascent. Further, the determinants to integrating PoC testing for HCV RNA into prison environments are unclear and there has been limited examinations of the cost implications of such interventions in UK prisons. This manuscript describes a pilot project in a Scottish prison which integrated PoC HCV RNA testing into routine on-site nurse-led care using the Cepheid GeneXpert platform with the Xpert® HCV VL Fingerstick assay.[15] The primary outcome of this study was to determine – for those who received a PoC test relative to those tested conventionally – if there was a difference in survival, measured in days, from a positive HCV RNA result and treatment initiation. Secondary outcomes were to: assess the cost of PoC RNA testing relative to conventional methods; and evaluate the determinants to implementing the PoC RNA testing platform.

Methods

Study design

This was a mixed-methods NHS service evaluation – with retrospective analysis of routine NHS HCV testing, treatment, and cost data, and prospective qualitative interviews – of a modified HCV care pathway in HMP Perth, a prison in central Scotland.[16,17] Caldicott Guardian approval was granted for data access (IGTCAL7004).[18] This process reviews internal NHS evaluations, ensuring the protection and appropriate use of patient data. The

evaluation was registered with the NHS clinical governance group for prison healthcare (ref: 27/19).

Patient and public involvement

Patients and members of the public were not involved in the design or conduct of this work.

Setting

NHS Tayside is a large health board are located on the East of Scotland. HMP Perth is a large maximum-security male prison in the NHS Tayside board area which houses people on mixed-duration sentences.[19] Healthcare is provided by the NHS from an on-site centre. Opt-out HCV testing is in place on reception to prison and includes conventional phlebotomy and dried blood spot (DBS) methods.[20] Prison staff escort individuals from the residential areas of the prison to BBV clinics. As a test of change, PoC HCV RNA testing was integrated into routine care in prison BBV clinics alongside conventional testing methods.

Participants

This study used existing service data for quantitative analysis. All adults (≥18 years) with detectable HCV RNA, and/or treated for HCV in HMP Perth from December 2018 to March 2021 were eligible for inclusion. The timeline for the study is shown in Figure 1. Data was collected for a one year 'pre-pilot' phase, when only conventional testing was offered, to compare against the pilot phase data. In the analysis, those tested during the pilot phase were grouped by whether they received a PoC test or a conventional test, for comparison. NHS Tayside staff members involved in any stage of the implementation process were eligible to participate in the prospective qualitative strand.

[Figure 1]

Clinical outcomes

Clinical outcomes were collected to inform the cost analysis. SVR was undetectable (<10 IU/mL) HCV RNA at least 12 weeks post-treatment. Relapse was undetectable RNA at end of treatment, but detectable prior to or at SVR; or treatment initiation and detectable RNA

prior to or at SVR, if end of treatment test not conducted. Loss to follow up (LTFU) was defined as no post-treatment RNA test on record up to and including the censor date.

Statistics

Descriptive statistics were undertaken to obtain relevant counts and rates. To assess the primary outcome, individuals were grouped depending on their test type (conventional or PoC) and when the test was taken (pre-pilot or during the pilot). Kaplan-Meier failure analysis and log-rank testing were undertaken, followed by Cox proportional hazards (PH) modelling. Two PH models were fit: one comparing the PoC group to the pre-pilot conventionally tested group; and one comparing the PoC group to those tested conventionally during the pilot. The terminating event was treatment initiation. To assess treatment opportunity loss during the pilot, equality of proportions who remained untreated between groups were tested using a two-sample test of proportions (*z* test). Statistical testing was undertaken using Stata BE 17. *P* values of ≤0.05 were assumed to demonstrate statistical significance.

Cost analysis

Although healthcare cost analyses typically express outcomes in quality-adjusted life years and willingness-to-pay thresholds,[21] it was not possible to collect the data for this type of analysis in this retrospective evaluation. Consequently, an incremental 'cost-per-SVR' approach was taken from an NHS perspective, where the costs of all HCV RNA test and treatment were summed and divided by the population benefits of linkage to care, i.e. obtaining SVR. Costs for all relevant sample types were obtained from the manufacturer or NHS department. Medication costs were estimated from the British National Formulary and published sources, and do not account for discounting in the primary calculations.[22-24] Staff time was costed proportionately in line with NHS agenda for change.[25] Estimates do not include sundry items and do not account for inflation. Those whose pre-treatment HCV RNA test could not be verified were excluded. The time horizon was the study period.

Qualitative methods

A convenience sample of NHS staff members (n=6) known to the research team, and involved in implementing the GeneXpert, were invited to participate in semi-structured interviews. Written informed consent was obtained. For practical reasons, focus groups were undertaken with nursing staff, while individual interviews were undertaken with others. These were recorded digitally and transcribed verbatim with identifying data censored. The Consolidated Framework for Implementation Research (CFIR) informed interview guide design and data analysis.[26] The CFIR is a meta typology composed of five major domains, which provides a structured and pragmatic approach for understanding real-world implementation initiatives.[26] It was selected for its systems-level approach, consistent with the NHS analytic perspective. Non-NHS staff and prison residents were not approached to participate as they were outwith the remit of NHS service evaluation.

Thematic analysis was undertaken to analyse interview data using a deductive approach.[27] Transcripts were read two times by the analyst (CJB) and coded for 'barrier' or 'facilitator'. A barrier was defined as any phenomenon that had an inferred negative impact on any aspect of implementation, real or abstract, conversely a facilitator was any phenomenon inferred to have had a positive impact. Once compiled, determinants were allocated to domains of the CFIR. Triangulation of determinants was performed on 20% of transcripts by an independent analyst (AM) according to a pre-determined algorithm. Divergences were discussed until consensus was reached and this informed coding of remaining transcripts. Analysis was on screen or paper, without use of analytic software.

Results

Primary outcomes

From December 2018 to March 2021 (Figure 1), 386 RNA tests were performed, which identified 91 (23.6%) RNA-positive cases requiring treatment. Of those 91, 70 (76.9%) were tested conventionally and 21 (23.1%) with the GeneXpert. Sixty-seven (73.6%) individuals started HCV treatment. Of those, seven (10.4%) had missing or unreliable testing data and were excluded, giving a total of 60 (89.6%) treated cases for the primary analysis. In total, 167 (43.3%) RNA tests conducted were administered using the Xpert® HCV VL Fingerstick assay. Of all Xpert® tests, 23 (13.8%) returned error results, and three (1.8%) returned invalid results, giving an overall test success rate of 84.4%. Error rates for conventional tests were not recorded on routine systems and therefore are unreported. Xpert® test failures were mostly related to manual handling of assay cartridges (n=24; 92.3%). Sixteen (9.6%) Xpert® tests were not recorded on electronic health records at the end of the pilot, while 12 (7.2%) had some level of inaccurate information on the electronic report.

Descriptive parameters for the analysed cohort who initiated treatment (n=60) are outlined in Table 1. Median age was 39 years, and most (70%) cases were HCV treatment naïve. The most frequent infection risk factor was IDU (91.7%). Most (60%) were in receipt of opioid agonist therapy (OAT), and there were no instances of diagnosed cirrhosis. The most common genotype was one (38.3%), followed by three (26.7%).

Table 1: Demographic and clinical characteristics of treated cases included in time-to-event analysis, 2018-21, HMP Perth, Tayside (n=60).

Parameter		Treated cases (n=60)
Gender – n (%)		
	Male	60 (100)
	Female	0 (0.0)
Age at RNA test – median (IQR)		39 (33.5-43.5)
Infection risk factor – n (%)		
	IDU	55 (91.7)
	Unknown	5 (8.3)
HCV genotype – n (%)		
	1	23 (38.3)
	2	1 (1.7)
	3	16 (26.7)
	unknown	20 (33.3)
Prior HCV treatment – n (%)		
	No	42 (70.0)
	Yes	18 (30.0)
OAT – n (%)		
	No	24 (40.0)
	Yes	36 (60.0)
Fibroscan (KpA) – median (IQR) †		5.7 (4.9-7.5)
Fib4 score – median (IQR) ‡		0.90 (0.54-1.34)
Cirrhosis diagnosis§– n (%)		
	No	60 (100.0)
	Yes	0 (0.0)

Abbreviations: HMP, Her Majesty's Prison; RNA, ribonucleic acid; IDU, injection drug use; HCV, hepatitis c virus; OAT, opioid agonist therapy; KpA, kilopascals; IQR, interquartile range.
†n=9
‡n=52
§Cases with Fib4 score ≤1.45 were assumed not have cirrhosis; for cases in the indeterminate Fib4 range, or cases with a score of ≥3.25, medical notes were manually reviewed to check for a diagnosis of cirrhosis by other means. Where Fib4 was not available, but Fibroscan was available, a score of ≥14kPa (F4) was used to define presence of cirrhosis, scores of <14kPa were assumed not to have cirrhosis. Cases with no assessments for liver stiffness (n=6) who commenced treatment with a standard duration (8 weeks) were assumed not to have cirrhosis.

Median survival to treatment was 33 (IQR 22-70) days for those conventionally tested from 2018-19; 50 (IQR 33-220) days for those tested conventionally during the pilot phase; and 19 (IQR 7-28) days for those tested using the GeneXpert during the pilot. These differences were statistically significant (X^2=13.10, p=.001). During the pilot phase specifically, 16 of 27 (59.3% [95%CI 40.7–77.8]) HCV RNA+ cases tested conventionally did not initiate

treatment. Among those tested using the Xpert® assay, five of 21 (23.8% [95%CI 5.59–42.0]) did not initiate treatment. This translated to a proportionate difference in loss to treatment of 35.5% (95%CI 9.46–61.43) which was statistically significant (z=2.47, p=.014). Clinical and other outcomes are shown in Figure 2.

[Figure 2]

PH modelling, adjusted for age, is shown in Table 2. Consistent with the shorter survival time observed, the hazard of treatment was higher for those tested with the GeneXpert in both models, with a higher hazard observed when comparing cases in the pilot phase directly (model 2).

Table 2: Proportional hazards models adjusted by age.

	Variable	n (%)	aHR (95%CI)	*p*
Model 1	Conventionally tested 2018-19 (ref)	36 (63.2)	…	
	GeneXpert tested 2019-21	21 (36.8)	1.91 (1.03–3.55)	.040
	Age at test	…	1.04 (1.00–1.08)	.051
Model 2	Conventional testing 2019-21 (ref)	27 (56.2)	…	
	GeneXpert tested 2019-21	21 (43.8)	3.76 (1.67–8.46)	.001
	Age at test	…	1.02 (0.97–1.09)	.396

Abbreviations: PH, Proportional hazards; aHR, adjusted hazard ratio; CI, confidence interval.
Model 1 fit: X^2=8.07, p=0.017. Harrell's C: 0.64 (95% CI 0.56-0.72), p = <.0001.
Model 1 survival information: n = 57; failures = 49; time at risk = 2,827 days.
Model 2 fit: X^2=10.93, p=0.004. Harrell's C: 0.68 (95% CI 0.58-0.78), p = <.0001.
Model 2 survival information: n = 48; failures = 27; time at risk = 2,458 days.

Secondary outcomes

In the cost analysis, the price per SVR was higher (Table 3) for those tested with the GeneXpert relative to conventional methods in both the pre-pilot phase (+£721.30, +1.9%) and the pilot phase (+£14,499.80, +60.7%). However, when maximum discount rates were applied to medication costs, and those who were LTFU post treatment were assumed to have achieved an SVR,[12] PoC testing costs became favourable per SVR achieved relative to the pre-pilot phase (-£148.51, -4.7%). That said, in this scenario, it remained unfavourable relative to conventional testing in the pilot phase (+£372.39, +14.1%).

Table 3: Incremental cost per cure over duration of study observation period by diagnostic test type and study phase.

Parameter	Conventional (2018-19)	Conventional (2019-21)	GeneXpert (2019-21)
RNA tests (n)	164†	55†	167
Testing‡	£9,140.61	£3,078.84	£6,656.62
Actual cost per test	£55.74	£55.98	£39.86
Medication§	£857,559.78¶	£259,866.60#	£415,786.56††
Total costs	£866,700.39	£262,945.44	£422,443.18
Total SVR (n)	23	11	11
Proportion tests, SVR	14%	20%	7%
Cost per SVR	£37,682.63	£23,904.13	£38,403.93
Discounted medication rates			
Per SVR/30% discount	£26,497.06	£16,816.86	£27,064.29
Per SVR/50% discount	£19,040.02	£12,092.01	£19,504.54
Per SVR/90% discount	£3,728.52	£2,642.32	£4,385.03
Discounted medication rates, all LTFU assumed cured			
Per SVR/0% discount	£28,890.01	£23,904.13	£26,402.70
Per SVR/30% discount	£20,314.42	£16,816.86	£18,606.70
Per SVR/50% discount	£14,597.35	£12,092.01	£13,034.37
Per SVR/90% discount	£3,163.22	£2,642.32	£3,014.71

†213 venepuncture samples and 6 dried blood spot samples sent for RNA testing.
‡Combined costs for RNA samples. Note that the cost per test was calculated by dividing the testing costs by the number of tests performed in each group.
§Combined costs at full list prices, estimated from British National Formulary online, and does not include any negotiated discounts.
¶Glecaprevir/pibrentasvir, 100/40mg at £12,993.66 per pack of 84, 8-week duration (n=32); sofosbuvir/ledipasvir 90/400mg at £12,993.33 per pack of 28, 8-week duration (n=1).
#Glecaprevir/pibrentasvir, 100/40mg at £12,993.66 per pack of 84, 8-week duration (n=9); Sofosbuvir/velpatasvir, 400/100mg at £12,993.33 per pack of 28 tablets, 8-week duration (n=1). Excludes treatment costs for one individual whose medication costs were not incurred by the health service.
††Glecaprevir/pibrentasvir, 100/40mg at £12,993.66 per pack of 84, 8-week duration (n=16).
Note: costs for testing are inclusive of staff time.
Abbreviations: RNA, ribonucleic acid; SVR, sustained virologic response.

In the qualitative analysis, five semi-structured interviews (two group, three individual) were undertaken with six staff involved in delivery of the prison HCV pathway, with representation from service leadership, laboratory, and nursing staff. Forty-one barriers and 29 facilitators were identified, giving a total of 70 determinants (Table S1 [Appendix S1]). The largest proportion of facilitators were within the *characteristics of individuals* CFIR domain, and barriers in the *inner setting* domain (Table 4).

Table 4: Proportion of implementation determinants in each CFIR domain.

Determinants	CFIR domain				
	Intervention characteristics	Outer setting	Inner setting	Characteristics of individuals	Process
Facilitators – n (%)	6 (20.7)	5 (17.2)	6 (20.7)	8 (27.6)	4 (13.8)
Barriers – n (%)	5 (12.2)	2 (4.9)	13 (31.7)	9 (21.9)	12 (29.3)

Abbreviations: CFIR, Consolidated Framework for Implementation Research.
Notes: Percentages are proportions of all barriers/facilitators across CFIR domains.

To briefly summarise some key determinants, the analysis highlighted concerns around the manual result notification process, which utilised an amended micro-biology sample processing form to notify PoC results to central laboratory staff, for example:

> *If that bit of paper goes missing, the result's missing […] there's potential for, like, transcription errors […] there is a temptation as well, if you're really busy, to put them on the backburner and leave them.*
>
> – Biomedical scientist

On the device itself, interpreting viral load quantification output on the GeneXpert raised issues, as it was difficult to understand:

> *I checked it yesterday, to go and just to see, it was like, '7.52e05'.*
>
> *That doesn't mean anything to anybody...*
>
> *The lab phoned for me […] they couldn't understand the result, they didn't know what it was […] it came up '7.52e', and they were querying that.*
>
> – Nurse

Also, there were perceived challenges around co-operative teamworking between NHS and prison staff in engaging prison residents in implementing HCV testing, including the PoC testing approach:

> *There's a lot of 'refusals' […] we've never been able to work out what that refusal is caused by […] they've now got to fill in a form to say why they refused, and they're not getting done.*
>
> – Nurse

Manual handling of assays and related consumables, particularly with respect to infection control, was a source of anxiety:

> *It's messy, with the fingerprick and things, it's messy […] from an infection control sense it's a lot messier.*
>
> *We don't want to damage that fin [on the assay]. I'm paranoid about that, I really am.*
>
> – Nurse

Over and above these barriers, there were concerns around integrating the GeneXpert into usual workflow, task prioritisation, and staff turnover (see Table S1 [Appendix S1]). On the other hand, the analysis uncovered multiple perceived facilitators of implementation, for example, the rapidity of results:

> *I was able to go and give them their results before I went home, so it's great!*
>
> – Nurse
>
> *You've got the difference between getting a result you can act upon, rather than having to wait a week. So, that's a major advantage.*
>
> – Leadership

Additionally, the increased flexibility in clinic times made possible by the option of PoC testing was viewed favourably:

> *That's a good point […] because the bloods go away [are sent to the laboratory] at half past 12. So, PCR really needs to be done in the morning.*
>
> *It wouldn't have to get sent off…*
>
> *It takes away all the barriers doesn't it*
>
> *…you can extend that clinic then. Into the afternoon because you've not got that cut-off at half past 12.*
>
> – Nurse

Perceived patient preferences, i.e. preferring capillary/fingerstick sampling to conventional phlebotomy, were seen as a facilitator to implementation, as nurses could engage individuals who were otherwise disinterested:

> *I've got one guy waiting for this machine because he refuses point-blank to get, get needles in him.*
>
> – Nurse

In addition to these key facilitators, supportive colleagues, the wider evidence base for PoC testing, and the mobility of the device were viewed as positively influential on implementing the GeneXpert in the prison.

Discussion

Interventions to enhance transition to HCV treatment are required for critical populations, including incarcerated people, if WHO 2030 elimination goals are to be realised.[28,29] This single-site evaluation has demonstrated that it is clinically beneficial to implement on-site nurse-led PoC RNA testing for HCV in a maximum-security Scottish prison with low error rates. One-hundred and sixty-seven PoC tests were administered and, among individuals who tested HCV positive, those who received one had increased likelihood of initiating treatment sooner than those tested conventionally. However, the analyses suggest that employing such an approach may not be cost favourable.

Price differences appeared sensitive to: a) the significant difference in linkage-to-treatment for the GeneXpert group relative to the conventional group in the pilot phase, which incurred higher treatment costs; b) the proportion of RNA tests in the pilot phase which were Xpert® rather than conventional, meaning higher overall testing costs, despite the lower cost-per-test at the individual level; and c) LTFU among those who started treatment, which was proportionally higher in the GeneXpert group (5/16; 38%), relative to those conventionally tested in pre-pilot (7/33; 21%) and pilot (0/11; 0%) phases. Improved linkage-to-treatment is important to consider when choosing whether to implement such interventions because, with the high efficacy of DAA treatment, LTFU individuals are likely to have achieved SVR.[12] The costs of a relatively less efficient pathway may be higher with respect to enduring HCV transmission and its attendant consequences. In the hypothesised scenario of maximum discounting of DAAs, and cure attainment among those LTFU, the GeneXpert group costs became favourable relative to the pre-pilot phase. For others considering a similar approach, consideration might be given to this, as well as the identified implementation determinants.

Bringing quickly actionable HCV testing closer to incarcerated people has been increasingly advocated in recent years.[30–32] The primary results reported here align with recent similar research. A study undertaken in HMP Wormwood Scrubs, England, reduced time from screening to treatment from three months, for those tested by DBS, to one week, by implementing PoC RNA testing and augmenting it with a streamlined care pathway.[33] However, processing of GeneXpert samples was not undertaken on site. Similarly, an Australian study, reported high test uptake and shortened transition to treatment among a cohort screened upon reception using a one-stop approach including PoC RNA testing with additional fast-track components. Initial results indicated those tested by PoC had shorter time from testing to treatment (6 v 90 days; $p<0.001$) as well as high treatment uptake, similar to our findings.[34] Although views of imprisoned people on the acceptability of PoC testing did not form part of the work undertaken here, other studies have examined this. A qualitative sub-study on the Australian project showed the PoC intervention was highly acceptable to participants.[35] Other work found testing in this manner highly acceptable, with most preferring it to venepuncture.[36] Further, a Canadian study found PoC fingerprick HCV testing was highly preferred to conventional venepuncture for those with challenging venous access, which we also observed in the qualitative analysis.[37]

Currently we know what works well for HCV diagnosis and treatment on a technical level.[38] Therefore, we have reported multiple determinants of implementation with the intention of informing projects undertaken elsewhere. Overall, the results implied an underlying tension between individual knowledge, self-efficacy, and organisational culture, with leadership, readiness to implement, and prioritisation of work. In the *inner setting*, most barriers were associated with the constrained nature in which clinical staff could operate within the prison; the relative priority of healthcare in the prison environment; staff turnover and training issues; and the relative priority of the pilot to laboratory staff. Most facilitators were in the *characteristics of individuals* domain. They predominantly spanned existing knowledge of the GeneXpert platform; prior experience with PoC testing for other clinical indications; a

perception of the GeneXpert as innovative and easing workloads; and a perceived openness to change among nursing staff. In *intervention characteristics*, staff felt the need to return to the device after 60 minutes to conclude the process was inconvenient relative to conventional methods. Further, the sensitivity of the assays to external forces; the way the device reports viral load quantification; and obtaining fingerprick samples were all observed as challenges.

Conversely, the evidence around the GeneXpert; the mobility of the device; its impact on clinic planning; and the rapidity of test results were all positive influences. In the *process* domain, the result reporting procedure, although effective, was less attractive than an automated electronic system. Finally, in the *outer setting*, professional regulations made it difficult to delegate certain tasks to alternative staff members, and impacts related to COVID-19 made the reporting workflow challenging to manage within the laboratory. Overall, in the wider regional context, the HCV elimination strategy in Tayside, along with the organisational structures which govern it, were seen as facilitative. We hope that by reporting the determinants of implementation against a recognised transferrable framework, we can increase their relevance across divergent settings and contribute to program design elsewhere.

This evaluation has multiple limitations. We were unable to seek the views of patients on the acceptability of PoC RNA testing, due to the nature of the work (NHS service evaluation, which permits interviewing of NHS staff on matters relating to the pilot, as opposed to prospective research with NHS patients, which requires enhanced review and approvals). Further, the sample who participated in qualitative interviews was inherently limited – almost all relevant staff (nurses, biomedical staff, service leadership, commissioning staff) participated – but may raise concerns regarding 'saturation'. However, given the specialised knowledge of participants; their relevance to the pathway; the use of an established theoretical framework; and a pre-specified analysis strategy, the concept of 'information power' is relevant.[39] This suggests the more information a sample holds, relevant to the

evaluation, and where scrutiny is informed by a theoretical framework, the fewer participants are required to 'saturate' the analysis. Other limitations include the impact of COVID-19 on laboratory testing turnaround times during the pilot, which may have disadvantaged the conventional group in the survival analysis, and the rudimentary approach to the cost analysis, which only included direct costs. Finally, the survival data frame was right censored for some cases, meaning their exact survival time was uncertain.

Conclusions

The results suggest that integrating the Cepheid GeneXpert platform into routine nurse-led HCV care in a maximum-security prison health centre improves linkage to treatment in the Scottish context. Our data augments the available literature with respect to the benefits of this approach on linkage to care, but reports gains which are more modest, possibly driven by the absence of additional care pathway changes reported by others. Multiple determinants to implementation were highlighted, which may inform similar pilots in other prisons. The new platform was less favourable in cost terms than conventional testing; however, this was sensitive to multiple factors, and in realistic hypothesised scenarios multiple favourable cost outcomes were observed. Consequent of this pilot, we are now undertaking further research informed by this work with this testing platform in local needle and syringe provision sites, and a comparable analysis is planned.

Appendices

Author contributions

CJB, SKI, and JFD conceptualised the evaluation. CJB curated data; selected the methodologies employed; undertook qualitative and quantitative analyses; visualised data; and wrote the original draft. SKI and JFD provided supervision. AM undertook to qualitative data analysis. All authors contributed to and approved the final version of the manuscript. CJB had full access to the data and takes responsibility for the integrity of the data and the accuracy of analysis.

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Competing interests

CJB, AM, and SKI, have no disclosures. JFD reports grants and personal fees from AbbVie; grants and personal fees from Gilead; and grants and personal fees from MSD, outside the submitted work.

Patient and public involvement

Patients and members of the public were not involved in the design or conduct of this work.

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Data availability statement

Quantitative data underpinning this study were obtained from routinely updated NHS health records in line with approval granted by the NHS Caldicott Guardian. The individuals to whom the data pertains did not explicitly consent to its use for research purposes. Therefore,

it is not possible for the authors to share this data. However, interested parties can make specific requests to NHS Tayside Information Governance by email on: informationgovernance.tayside@nhs.scot. Consideration will be given to sharing qualitative data upon receipt of a methodologically sound proposal and will be subject to the agreement of interview participants.

Ethics Approval

As this was a retrospective service evaluation, NHS ethical review was not required. Instead, Caldicott Guardian approval was obtained for data access (IGTCAL7004). This process reviews internal NHS evaluations, ensuring the protection and appropriate use of patient data. The evaluation was also registered with the NHS Tayside clinical governance group for prison healthcare (ref: 27/19).

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Figure legends

Figure 1: Summary of observation dates and study activities.

Note: Conventional testing was by whole blood sent to a laboratory for analysis and dried blood spot methods.

Figure 2: Target cohort profile with related clinical outcomes and censoring.

*Cases received treatment but excluded from cost and time-to-treatment analyses, as their testing data was unavailable or unverifiable.

†All censored in survival analysis at relevant decease, liberation, transfer, or follow-up censor dates.

Notes: Group 1 are those tested conventionally from 2018-19 (reference period); group 2 are those conventionally tested during the pilot phase (2019-21); group 3 are those tested with the GeneXpert during the pilot phase (2019-21).

Abbreviations: RNA, ribonucleic acid; RNA+, ribonucleic acid positive (actively infected); SVR, sustained virologic response; LTFU; lost to follow up.

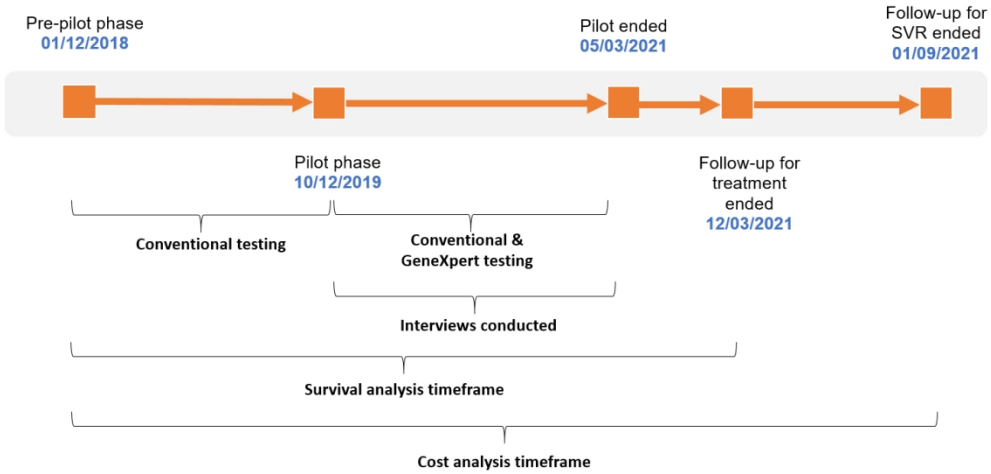

Figure 1: Summary of observation dates and study activities.

971x468mm (38 x 38 DPI)

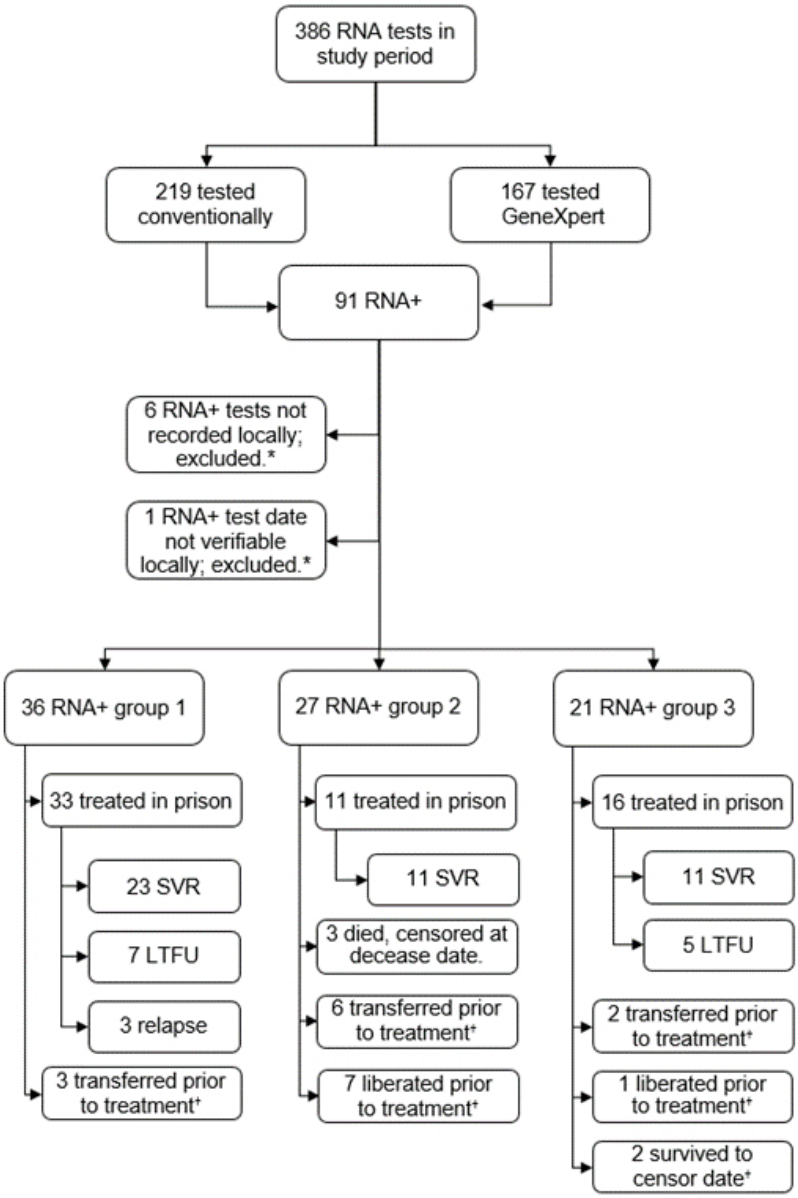

Figure 2: Target cohort profile with related clinical outcomes and censoring.

347x508mm (38 x 38 DPI)

Supplementary file 1

A mixed-methods evaluation of point-of-care hepatitis c virus RNA testing in a Scottish Prison.

Christopher J Byrne[1,2] Amy Malaguti[3,4] Sarah K Inglis[2] John F Dillon[1,5]

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Table S1: List of all determinants to implementation of the Cepheid GeneXpert in HMP Perth identified in semi-structured staff interviews(n=70).

Domain	Barriers (n=41)
Inner setting	Leadership staff felt individual custody trumped healthcare in the prison, hindering improvements to care.
	Laboratory staff did not prioritise uploading GeneXpert results as they did not perform the test.
	Laboratory staff did not prioritise reporting GeneXpert results because it was a pilot project.
	Leadership staff felt that, as the nurses were not present for the majority of admissions, in-reach was limited.
	Leadership staff felt a lack of freedom to operate in the prison hindered the design of the pathway.
	Clinical staff felt the lack of physical space and clinic rooms adversely affected how and when the GeneXpert could be used.
	Clinical staff were limited to using the GeneXpert and obtaining samples for testing in specific locations in the prison.
	Clinical staff found it difficult to transit individuals from residential areas of the prison the health centre due to the need for intermediary 'runners'.
	Clinical staff felt pressured by SPS staff to finish clinic appointments quickly.
	Clinical staff found it difficult to implement healthcare initiatives as it was perceived as secondary to the regimental running of the prison/security.
	Clinical staff found it difficult to engage colleagues outside their direct team in HCV testing due to perceived lack of integrated care.
	The GeneXpert was seen as difficult to implement in the long-term due to high staff turnover in the prison.
	Laboratory staff found it difficult to log results in a timely manner due to staff turnover and training issues.
Outer setting	Laboratory staff felt uncertainty around whether reporting tasks could be delegated to administrative staff due to professional regulations.
	Laboratory staff found it difficult to manage the reporting workflow due to the pressures of the Covid-19 pandemic.
Characteristics of Individuals	Leadership staff felt a lack of awareness of HCV among people in prison and prison staff hindered improvements to prison care.
	Laboratory staff did not see administration of GeneXpert results as part of their job/in line with their skillset.
	Laboratory staff felt uncertain about the value of their role in the reporting process.
	Clinical staff felt cynical about whether SPS staff 'runners' actually approached individuals to inform them their attendance at the health centre was required.
	Clinical staff indicated a preference to obtain a venous sample to fingerprick sample due to their self-perceived proficiency at obtaining venous bloods.
	Clinical staff viewed fingerprick sampling method as slower than obtaining venous samples.
	Clinical staff often wanted to know antibody status of an individual, meaning at times they may not have prioritised PCR testing with GeneXpert.

	Clinical staff felt obtaining fingerpick samples using the minivette introduced infection control concerns.
	Laboratory staff felt unsure about the value of their role in the result reporting process.
Intervention characteristics	Leadership staff felt the need to return to device to check result after one hour made it difficult to plan work for a clinic when they had competing priorities for their time.
	Performing a GeneXpert test was perceived as more work than obtaining conventional samples and sending them for lab analysis, by leadership staff.
	Transporting GeneXpert test assays in the prison caused anxiety for clinical staff due to the sensitivity of the rear fin on the cartridge.
	Clinical staff felt the dexterity required to correctly insert the sample into the cartridge caused errors in results.
	Laboratory and clinical staff found it challenging to interpret the viral load quantification output (scientific notation) from the device.
Process	Laboratory staff felt the lack of an IT link raised concerns about accurate result reporting.
	Laboratory staff found it difficult to plan/implement an SOP for reporting results, as they were unsure what to expect in terms of volume of tests.
	Clinical staff had difficulty conceptualising how the device would be used due to a lack of a plan on who to target for testing and how to do so.
	Clinical staff found it difficult to plan a 'one-day' test/treat pathway due to safety concerns with the frontline medication used.
	Clinical staff found it difficult to transit individuals to the prison health centre due to the provision of OST at concurrent time to BBV clinics.
	The GeneXpert process was viewed as time-consuming difficult to implement systematically due to unpredictable nurse workload.
	Laboratory staff did not prioritise uploading test results to electronic systems because they did not perform the test themselves.
	The paper reporting process was felt to introduce potential for result reporting/transcription errors.
	Laboratory staff found it difficult to adapt to the paper/manual reporting workflow as it was unfamiliar to them.
	Laboratory staff felt there was poor communication between themselves and clinical staff implementing the testing.
	Clinical staff found it difficult to verify patients' CHI numbers as they are not routinely used in the prison system.
	Clinical staff were anxious about the paper reporting process because it placed a high degree of responsibility on them not to make reporting errors.

	Facilitators (n=29)
Inner setting	Laboratory staff were open to challenge on results incorrectly uploaded due to their perceived professional responsibility to ensure accuracy. Clinical staff found it easier to plan engagement with testing by co-designing awareness materials with people in prison. Clinical staff found it easier to implement the GeneXpert pathway because of previous testing undertaken in the prison for diabetes by another team. Clinical staff found it easier to navigate the prison environment for testing after being 'key trained'. The prison BBV nursing team's openness to change and credibility with prison staff was perceived as helpful to implementation, by leadership staff. Clinical staff found it easier to engage patients due to the ethos of their team which values individual relationships.
Outer setting	The local HCV elimination strategy was seen as facilitative of improving care by leadership staff. MCN infrastructure and inter-organisational working was seen as facilitative of improving prison BBV care by leadership staff. GeneXpert was viewed as preferable for sampling in patients with difficult venous access by clinical staff. Some people in prison indicated a preference to clinical staff to be tested using the GeneXpert due to the non-invasive sampling. Clinical staff found it easier to implement the GeneXpert pathway as the virology team were perceived as supportive.
Characteristics of Individuals	Laboratory staff felt prior experience with reference result reporting and prior PoC pilots for flu were helpful in implementing the result reporting workflow for the GeneXpert. Laboratory staff appreciated the unique testing challenges in the prison environment. Laboratory staff perceived GeneXpert testing in the prison as innovative. Wider knowledge of GeneXpert testing in other UK cities among laboratory staff and individual advocacy among those staff facilitated the decision to support the project. Clinical staff trusted the results from the GeneXpert due to an awareness other teams were using them. Clinical staff perceived the GeneXpert as making their job easier. New staff in the prison health centre were perceived as being open to change by existing clinical staff. Clinical staff perceived the GeneXpert as enabling quicker transition from diagnosis to treatment.
Intervention characteristics	Leadership staff felt the strong existing evidence base on the clinical effectiveness of the GeneXpert and benefits of HCV treatment for PWID facilitated implementation. Laboratory staff found it easier to integrate the GeneXpert as there were no financial implications to do so. Clinical staff found it easier plan their use of the GeneXpert as it was mobile (on trolley).

	Clinical staff could plan afternoon clinics/more flexible clinic times as the GeneXpert made the 12.30 bloods cut-off inapplicable for PCRs. Leadership staff felt that GeneXpert delivered quick, actionable, results and was easy to use. GeneXpert was perceived as preferable to conventional testing due to the speed of the results by leadership staff.
Process	Laboratory staff felt existing lab systems could be easily amended to integrate the GeneXpert test platform. Clinical staff found it easier to engage people in prison into testing by building rapport with and disseminating HCV information via 'pass men'. Laboratory staff felt integrating the GeneXpert process as a whole was minimally disruptive to their usual work. Laboratory staff felt it was an easier process compared to conventional testing as they did not have to process the samples themselves.

Abbreviations: HMP, Her Majesty's Prison Service; HCV, hepatitis c virus infection; IT, information technology; SOP, standard operating procedure; OST, opioid substitution therapy; BBV, blood-borne virus; SPS, Scottish Prison Service; CHI, community health index; MCN, managed care network; PoC, point-of-care; UK, United Kingdom; PWID, people who inject drugs; PCR, polymerase chain reaction.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	PAGE
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6-9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-9
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	7
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-9
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	8
		(*c*) Explain how missing data were addressed	8
		(*d*) If applicable, explain how loss to follow-up was addressed	8
		(*e*) Describe any sensitivity analyses	…
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	10
		(c) Consider use of a flow diagram	Fig 2
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10; table 1
		(b) Indicate number of participants with missing data for each variable of interest	10-11; Fig 2
		(c) Summarise follow-up time (eg, average and total amount)	10; table 2
Outcome data	15*	Report numbers of outcome events or summary measures over time	10-12
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted	10-12;

		estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	table 2
		(*b*) Report category boundaries when continuous variables were categorized	…
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	…
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	12-16
Discussion			
Key results	18	Summarise key results with reference to study objectives	16
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	18-19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	19
Generalisability	21	Discuss the generalisability (external validity) of the study results	4
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	20

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

BMJ Open

A mixed-methods evaluation of point-of-care hepatitis c virus RNA testing in a Scottish prison.

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Title

A mixed-methods evaluation of point-of-care hepatitis c virus RNA testing in a Scottish prison.

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Abstract

Objectives

Hepatitis C Virus (HCV) poses a global public health threat. Prisons are a focus of prevention efforts due to high infection burdens. Expedition of treatment for incarcerated people is critical, as many are short-term sentenced. We evaluated point-of-care (PoC) HCV RNA testing in a maximum-security Scottish prison and assessed its impact on transition to treatment. We also evaluated costs and determinants of implementation.

Design

Mixed-methods evaluation of a single-centre care pathway pilot using NHS service data from 2018-21. Descriptive statistics and survival analysis were undertaken. Cost analysis was assessed from a provider perspective. Healthcare staff participated in semi-structured interviews and thematic analysis with a deductive approach was undertaken to identify implementation determinants.

Setting

A large maximum-security Scottish prison health centre administered by the NHS.

Participants

296 incarcerated NHS patients (all male) and six NHS staff members (two male, four female).

Interventions

Hepatitis C Virus (HCV) testing using the Cepheid GeneXpert platform with Xpert® HCV VL Fingerstick assay.

Outcome measures

The main outcome was survival (in days) from HCV test to treatment initiation. Secondary outcomes were cost-per-cure obtained and implementation determinants.

Results

During the pilot, 167 Xpert® tests were administered, with an 84% completion rate, and treatment transition was superior for those who received it (*p*=.014). Where PoC tests were administered, shorter survival to treatment was observed (19 vs 33 days: *a*HR 1.91 [1.03-3.55], *p*=.040; 19 vs 50 days; *a*HR 3.76 [1.67-8.46], *p*=.001). PoC was costlier than conventional testing. In qualitative analysis, most facilitators were observed among characteristics of individuals domain whilst most barriers were noted in the inner setting.

Conclusions

Integrating PoC HCV RNA diagnosis into nurse-led HCV care in a maximum-security prison health centre shortens survival to HCV treatment. However, there are cost implications to this approach and multiple determinants that impact upon implementation should be addressed.

Strengths and Limitations of this study

- The study is strengthened by assessing the feasibility of point-of-care (PoC) testing from multiple angles which address clinical impact, costs to the health service, and barriers and facilitators to implementation, giving a holistic view of this approach.
- In contrast to other similar work, a strength of this study is that PoC testing was administered by nurses in the prison health centre.
- The study is limited by a small sample in the qualitative component, and its single-centre nature, which both restrict the generalisability of the findings.
- The study is further limited by only including NHS staff in the qualitative component.

Introduction

Hepatitis C Virus (HCV) infection is an enduring global public health threat. For those infected, in the absence of diagnosis and linkage to treatment, it can cause long-term negative health outcomes, such as progression of liver fibrosis to eventual cirrhosis, decreased health-related quality of life, and extra-hepatic sequelae such as renal or cardiovascular impairment. Prisons have been an important focus of HCV prevention efforts due to their high HCV burden relative to the general population, which intersects with the large number of people who inject drugs (PWID) who are imprisoned.[1] Imprisonment rates among PWID are substantial, with up to 58% estimated to have ever been incarcerated.[2] Further figures suggest that up to 38% of incarcerated people may have been exposed to HCV, due to the overlapping nature of injection drug use (IDU) and incarceration, and the absence of primary prevention measures for PWID whilst incarcerated.[3,4] Sharing of non-sterile injecting equipment in prisons is the leading cause of HCV transmission.[2] A previous study of Scottish prisons found that 32% of people in prison had a history of IDU and, among those, HCV prevalence was 53%.[5]

Recent data indicate that approximately 71% of individuals test positive for illicit substances upon reception to Scottish prisons; of those, 29% test positive for opioids and 24% for cocaine, which are commonly injected.[6] In the prison in this evaluation, approximately 38% and 18% of individuals tested positive for these respectively upon reception, implying an ongoing risk of blood-borne virus (BBV) transmission.[6] The Scottish justice system has a 'remand problem', defined as imprisonment awaiting sentence for 40-140 days.[7,8] In recent data, which spans the pilot period of this project, those identified as being in the part-year prison population across the prison estate, i.e. residing in a given establishment for less than one whole year, was estimated at 80.2%.[9] Recent figures for His Majesty's Prison (HMP) Perth, the prison in this pilot, estimated the remand population at approximately 22.8%.[10] These figures suggest substantial proportions of the prison population are highly transient, at risk of HCV transmission, with a short time-frame for healthcare engagement.

In the context of HCV, expedition of treatment for incarcerated persons is important to avoid loss to the system. Treating HCV-infected individuals whilst incarcerated has been identified as an important engagement strategy for people otherwise disconnected from conventional healthcare.[11] HCV treatment duration is relatively fixed, which leaves diagnosis as the key remaining modifiable care component.[12] Particularly in the absence of enhanced harm reduction supports to reduce risk, which are scarcely available in prisons.[13] This is especially pertinent to Tayside because Dundee, whose population is served by the prison in this evaluation, has the highest rate of incarceration per head of population in Scotland, as well as a historically high burden of HCV infection.[9,14] Consequent to this historically high HCV burden, Tayside has a suite of well-developed community care pathways which offer HCV care from multiple environments. Those affected by BBVs, such as HCV, who are liberated from HMP Perth to the local area are appointed to nurse-led community outreach clinics or local pharmacies for treatment continuation or post-treatment follow up after liberation.

In recent years, point-of-care (PoC) HCV testing platforms have become available which could ameliorate time burdens associated with existing testing methods and streamline linkage to treatment. However, the evidence documenting the impact these devices have in real-world prison contexts is nascent. Further, the determinants to integrating PoC testing for HCV RNA into prison environments are unclear and there has been limited examinations of the cost implications of such interventions in UK prisons. This manuscript describes a pilot project in a Scottish prison which integrated PoC HCV RNA testing into routine on-site nurse-led care using the Cepheid GeneXpert platform with the Xpert® HCV VL Fingerstick assay.[15] The primary outcome of this study was to determine if there was a difference in survival, measured in days, from a positive HCV RNA result and treatment initiation, among those who received a PoC test relative to those tested conventionally. Secondary outcomes were to: assess the cost of PoC RNA testing relative to conventional methods; and evaluate the determinants to implementing the PoC RNA testing platform.

Methods

Study design

This was a mixed-methods NHS service evaluation – with retrospective analysis of routine NHS HCV testing, treatment, and cost data, and prospective qualitative interviews – of a modified HCV care pathway in HMP Perth, a prison in central Scotland.[16,17] Accordingly, no randomisation, masking, or allocation to alternating interventions were undertaken as part of this pilot (choice of test rested with practitioner/patient). Caldicott Guardian approval was granted for data access (IGTCAL7004).[18] This process reviews internal NHS evaluations, ensuring the protection and appropriate use of patient data. The evaluation was registered with the NHS clinical governance group for prison healthcare (ref: 27/19).

Patient and public involvement

Patients and members of the public were not involved in the design or conduct of this work.

Setting

NHS Tayside is a large health board are located on the East of Scotland. HMP Perth is a large maximum-security male prison in the NHS Tayside board area which houses people on mixed-duration sentences.[19] Healthcare is provided by the NHS from an on-site centre. Opt-out HCV testing is in place on reception to prison and includes conventional phlebotomy and dried blood spot (DBS) methods.[20] Prison staff escort individuals from the residential areas of the prison to BBV clinics. As a test of change, PoC HCV RNA testing was integrated into routine care in prison BBV clinics alongside conventional testing methods.

Participants

This study used existing service data for quantitative analysis. All adults (≥18 years) with detectable HCV RNA, and/or treated for HCV in HMP Perth from December 2018 to March 2021 were eligible for inclusion. The timeline for the study is shown in Figure 1. Data was collected for a one year ‘pre-pilot’ phase, when only conventional testing was offered, to compare against the pilot phase data. In the analysis, those tested during the pilot phase were grouped by whether they received a PoC test or a conventional test, for comparison.

NHS Tayside staff members involved in any stage of the implementation process were eligible to participate in the prospective qualitative strand.

[Figure 1]

Clinical outcomes

Clinical outcomes were collected to inform the cost analysis. SVR was undetectable (<10 IU/mL) HCV RNA at least 12 weeks post-treatment. Relapse was undetectable RNA at end of treatment, but detectable prior to or at SVR; or treatment initiation and detectable RNA prior to or at SVR, if end of treatment test not conducted. Loss to follow up (LTFU) was defined as no post-treatment RNA test on record up to and including the censor date.

Statistics

Descriptive statistics were undertaken to obtain relevant counts and proportions. To assess the primary outcome, individuals were grouped depending on their test type (conventional or PoC) and when the test was taken (pre-pilot or during the pilot). Kaplan-Meier failure analysis and log-rank testing were undertaken, followed by Cox proportional hazards (PH) modelling. Two PH models were fit: one comparing the PoC group to the pre-pilot conventionally tested group; and one comparing the PoC group to those tested conventionally during the pilot. This strategy was chosen for two reasons: 1) to account for any changes to service delivery beyond our control during the pilot period (for example anything implemented by the prison service), and 2) the COVID-19 pandemic occurred during the pilot, which impacted upon laboratory test turnaround times. We sought to ensure any effect observed was independent of this lag. Models were also adjusted for age, as a proxy for potential transience through the prison (in the absence of sentencing data, and based on the experience of the project team). Limited models were also performed (Table S1 [Appendix S1]) with straightforward comparisons based on test type alone. The terminating event was treatment initiation. To assess treatment opportunity loss during the pilot, equality of proportions who remained untreated between groups were tested using a

two-sample test of proportions (*z* test). Statistical testing was undertaken using Stata BE 17. *P* values of ≤0.05 were assumed to demonstrate statistical significance.

Cost analysis

Although healthcare cost analyses typically express outcomes in quality-adjusted life years and willingness-to-pay thresholds,[21] it was not possible to collect the data for this type of analysis in this retrospective evaluation. Consequently, an incremental 'cost-per-SVR' approach was taken from an NHS perspective, where the costs of all HCV RNA test and treatment were summed and divided by the population benefits of linkage to care, i.e. obtaining SVR. Costs for all relevant sample types were obtained from the manufacturer or NHS department. Medication costs were estimated from the British National Formulary and published sources, and do not account for discounting in the primary calculations.[22-24] Staff time was costed proportionately in line with NHS agenda for change.[25] Estimates do not include sundry items and do not account for inflation. Those whose pre-treatment HCV RNA test could not be verified were excluded. The time horizon was the study period.

Qualitative methods

A convenience sample of NHS staff members (n=8) known to the research team, and involved in implementing the GeneXpert, were invited to participate in semi-structured interviews. Written informed consent was obtained. For practical reasons, focus groups were undertaken with nursing staff, while individual interviews were undertaken with others. These were recorded digitally and transcribed verbatim with identifying data censored. The Consolidated Framework for Implementation Research (CFIR) informed interview guide design and data analysis.[26] The CFIR is a meta typology composed of five major domains, which provides a structured and pragmatic approach for understanding real-world implementation initiatives.[26] It was selected for its systems-level approach, consistent with the NHS analytic perspective. Non-NHS staff and prison residents were not approached to participate as they were outwith the remit of NHS service evaluation.

Thematic analysis was undertaken to analyse interview data using a deductive approach.[27] Transcripts were read two times by the analyst (CJB) and coded for 'barrier' or 'facilitator'. A barrier was defined as any phenomenon that had an inferred negative impact on any aspect of implementation, real or abstract, conversely a facilitator was any phenomenon inferred to have had a positive impact. Once compiled, determinants were allocated to domains of the CFIR. Triangulation of determinants was performed on 20% of transcripts by an independent analyst (AM) according to a pre-determined algorithm (Figure S1, [Appendix S1]). Divergences were discussed until consensus was reached and this informed coding of remaining transcripts. Analysis was on screen or paper, without use of analytic software.

Results

Primary outcomes

From December 2018 to March 2021 (Figure 1), 386 RNA tests were performed, which identified 91 (23.6%) RNA-positive cases requiring treatment. Of those 91, 70 (76.9%) were tested conventionally and 21 (23.1%) with the GeneXpert. Sixty-seven (73.6%) individuals started HCV treatment. Of those, seven (10.4%) had missing or unreliable testing data and were excluded, giving a total of 60 (89.6%) treated cases for the primary analysis. In total, 167 (43.3%) RNA tests conducted were administered using the Xpert® HCV VL Fingerstick assay. Of all Xpert® tests, 23 (13.8%) returned error and three (1.8%) returned invalid results, giving an overall test completion rate of 84.4%. The 26 failed tests occurred among 20 patients. Of those, 15 patients had evidence of re-testing using the GeneXpert, consuming 18 Xpert® assays (repeat errors), whilst five had conventional blood draw. Generally, the quantity of failed tests decreased over time (Figure S2 [Appendix S1]). Error rates for conventional tests were not recorded on routine systems and therefore are unreported. Xpert® test failures were mostly related to manual handling of assay cartridges (n=24; 92.3%). Sixteen (9.6%) Xpert® tests were not recorded on electronic health records at the end of the pilot, while 12 (7.2%) had some level of inaccurate information (Table S2 [Appendix S1]) on the electronic report. This most frequently occurred when testing was re-

initiated following a short pause on clinical activities triggered by initial COVID-19 pandemic (Figure S3 [Appendix S1]).

Descriptive parameters for the analysed cohort who initiated treatment (n=60) are outlined in Table 1. Median age was 39 years, and most (70%) cases were HCV treatment naïve. The most frequent infection risk factor was IDU (91.7%). Most (60%) were in receipt of opioid agonist therapy (OAT), and there were no instances of diagnosed cirrhosis. The most common genotype was one (38.3%), followed by three (26.7%).

Table 1: Demographic and clinical characteristics of treated cases included in time-to-event analysis, 2018-21, HMP Perth, Tayside (n=60).

Parameter	Treated cases (n=60)
Gender – n (%)	
Male	60 (100)
Female	0 (0.0)
Age at RNA test – median (IQR)	39 (33.5-43.5)
Infection risk factor – n (%)	
IDU	55 (91.7)
Unknown	5 (8.3)
HCV genotype – n (%)	
1	23 (38.3)
2	1 (1.7)
3	16 (26.7)
unknown	20 (33.3)
Prior HCV treatment – n (%)	
No	42 (70.0)
Yes	18 (30.0)
OAT – n (%)	
No	24 (40.0)
Yes	36 (60.0)
Fibroscan (KpA) – median (IQR) †	5.7 (4.9-7.5)
Fib4 score – median (IQR) ‡	0.90 (0.54-1.34)
Cirrhosis diagnosis§– n (%)	
No	60 (100.0)
Yes	0 (0.0)

Abbreviations: HMP, Her Majesty's Prison; RNA, ribonucleic acid; IDU, injection drug use; HCV, hepatitis c virus; OAT, opioid agonist therapy; KpA, kilopascals; IQR, interquartile range.
†n=9
‡n=52

§Cases with Fib4 score ≤1.45 were assumed not have cirrhosis; for cases in the indeterminate Fib4 range, or cases with a score of ≥3.25, medical notes were manually reviewed to check for a diagnosis of cirrhosis by other means. Where Fib4 was not available, but Fibroscan was available, a score of ≥14kPa (F4) was used to define presence of cirrhosis, scores of <14kPa were assumed not to have cirrhosis. Cases with no assessments for liver stiffness (n=6) who commenced treatment with a standard duration (8 weeks) were assumed not to have cirrhosis.

Time to treatment was 33 (IQR 22-70) days for those conventionally tested from 2018-19; 50 (IQR 33-220) days for those tested conventionally during the pilot phase; and 19 (IQR 7-28) days for those tested using the GeneXpert during the pilot. These differences were statistically significant (X^2=13.10, p=.001). During the pilot phase specifically, 16 of 27 (59.3% [95%CI 40.7–77.8]) HCV RNA+ cases tested conventionally did not initiate treatment. Among those tested using the Xpert® assay, five of 21 (23.8% [95%CI 5.59–42.0]) did not initiate treatment. This translated to a proportionate difference in loss to treatment of 35.5% (95%CI 9.46–61.43) which was statistically significant (z=2.47, p=.014). Clinical and other outcomes are shown in Figure 2.

[Figure 2]

PH modelling, adjusted for age, is shown in Table 2. Consistent with the shorter survival time observed, the hazard of treatment was higher for those tested with the GeneXpert in both models, with a higher hazard observed when comparing cases in the pilot phase directly (model 2).

Table 2: Proportional hazards models adjusted by age.

	Variable	n (%)	aHR (95%CI)	*p*
Model 1	Conventionally tested 2018-19 (ref)	36 (63.2)	…	
	GeneXpert tested 2019-21	21 (36.8)	1.91 (1.03–3.55)	.040
	Age at test	…	1.04 (1.00–1.08)	.051
Model 2	Conventional testing 2019-21 (ref)	27 (56.2)	…	
	GeneXpert tested 2019-21	21 (43.8)	3.76 (1.67–8.46)	.001
	Age at test	…	1.02 (0.97–1.09)	.396

Abbreviations: PH, Proportional hazards; aHR, adjusted hazard ratio; CI, confidence interval.
Model 1 fit: X^2=8.07, p=0.017. Harrell's C: 0.64 (95% CI 0.56-0.72), p = <.0001.
Model 1 survival information: n = 57; failures = 49; time at risk = 2,827 days.
Model 2 fit: X^2=10.93, p=0.004. Harrell's C: 0.68 (95% CI 0.58-0.78), p = <.0001.
Model 2 survival information: n = 48; failures = 27; time at risk = 2,458 days.

Secondary outcomes

In the cost analysis, the price per SVR was higher (Table 3) for those tested with the GeneXpert relative to conventional methods in both the pre-pilot phase (+£721.30, +1.9%) and the pilot phase (+£14,499.80, +60.7%). However, when maximum discount rates were applied to medication costs, and those who were LTFU post treatment were assumed to have achieved an SVR,[12] PoC testing costs became favourable per SVR achieved relative to the pre-pilot phase (-£148.51, -4.7%). That said, in this scenario, it remained unfavourable relative to conventional testing in the pilot phase (+£372.39, +14.1%). Re-testing with the Xpert® assay, following a failed test, contributed roughly £717 of additional cost.

Table 3: Incremental cost per cure over duration of study observation period by diagnostic test type and study phase.

Parameter	Conventional (2018-19)	Conventional (2019-21)	GeneXpert (2019-21)
RNA tests (n)	164†	55†	167
Testing‡	£9,140.61	£3,078.84	£6,656.62
Actual cost per test	£55.74	£55.98	£39.86
Medication§	£857,559.78¶	£259,866.60#	£415,786.56††
Total costs	£866,700.39	£262,945.44	£422,443.18
Total SVR (n)	23	11	11
Proportion tests, SVR	14%	20%	7%
Cost per SVR	£37,682.63	£23,904.13	£38,403.93
Discounted medication rates			
Per SVR/30% discount	£26,497.06	£16,816.86	£27,064.29
Per SVR/50% discount	£19,040.02	£12,092.01	£19,504.54
Per SVR/90% discount	£3,728.52	£2,642.32	£4,385.03
Discounted medication rates, all LTFU assumed cured			
Per SVR/0% discount	£28,890.01	£23,904.13	£26,402.70
Per SVR/30% discount	£20,314.42	£16,816.86	£18,606.70
Per SVR/50% discount	£14,597.35	£12,092.01	£13,034.37
Per SVR/90% discount	£3,163.22	£2,642.32	£3,014.71

†213 venepuncture samples and 6 dried blood spot samples sent for RNA testing.
‡Combined costs for RNA samples. Note that the cost per test was calculated by dividing the testing costs by the number of tests performed in each group.
§Combined costs at full list prices, estimated from British National Formulary online, and does not include any negotiated discounts.
¶Glecaprevir/pibrentasvir, 100/40mg at £12,993.66 per pack of 84, 8-week duration (n=32); sofosbuvir/ledipasvir 90/400mg at £12,993.33 per pack of 28, 8-week duration (n=1).
#Glecaprevir/pibrentasvir, 100/40mg at £12,993.66 per pack of 84, 8-week duration (n=9); Sofosbuvir/velpatasvir, 400/100mg at £12,993.33 per pack of 28 tablets, 8-week duration (n=1). Excludes treatment costs for one individual whose medication costs were not incurred by the health service.

††Glecaprevir/pibrentasvir, 100/40mg at £12,993.66 per pack of 84, 8-week duration (n=16).
Note: costs for testing are inclusive of staff time.
Abbreviations: RNA, ribonucleic acid; SVR, sustained virologic response.

In the qualitative analysis, six (75%) of eight invited staff involved in delivery of the prison HCV pathway participated in five semi-structured interviews (two group, three individual), with representation from service leadership, laboratory, and nursing staff. The largest proportion of facilitators were within the *characteristics of individuals* CFIR domain, and barriers in the *inner setting* domain (Table 4).

Table 4: Proportion of implementation determinants in each CFIR domain.

Determinants	**CFIR domain**				
	Intervention characteristics	Outer setting	Inner setting	Characteristics of individuals	Process
Facilitators – n (%)	6 (20.7)	5 (17.2)	6 (20.7)	8 (27.6)	4 (13.8)
Barriers – n (%)	5 (12.2)	2 (4.9)	13 (31.7)	9 (21.9)	12 (29.3)

Abbreviations: CFIR, Consolidated Framework for Implementation Research.
Notes: Percentages are proportions of all barriers/facilitators across CFIR domains.

In total, 41 barriers and 29 facilitators were identified (Table 5). To briefly summarise some key determinants, the analysis highlighted concerns around the manual result notification process, which utilised an amended micro-biology sample processing form to notify PoC results to central laboratory staff, for example:

> *If that bit of paper goes missing, the result's missing […] there's potential for, like, transcription errors […] there is a temptation as well, if you're really busy, to put them on the backburner and leave them.*
>
> – Biomedical scientist

On the device itself, interpreting viral load quantification output on the GeneXpert raised issues, as it was difficult to understand:

> *I checked it yesterday, to go and just to see, it was like, '7.52e05'.*
>
> *That doesn't mean anything to anybody...*
>
> *The lab phoned for me […] they couldn't understand the result, they didn't know what it was […] it came up '7.52e', and they were querying that.*
>
> – Nurse

Also, there were perceived challenges around co-operative teamworking between NHS and prison staff in engaging prison residents in implementing HCV testing, including the PoC testing approach:

> *There's a lot of 'refusals' […] we've never been able to work out what that refusal is caused by […] they've now got to fill in a form to say why they refused, and they're not getting done.*
>
> – Nurse

Manual handling of assays and related consumables, particularly with respect to infection control, was a source of anxiety:

> *It's messy, with the fingerprick and things, it's messy […] from an infection control sense it's a lot messier.*
>
> *We don't want to damage that fin [on the assay]. I'm paranoid about that, I really am.*
>
> – Nurse

Over and above these barriers, there were concerns around integrating the GeneXpert into usual workflow, task prioritisation, and staff turnover (see Table 5). On the other hand, the analysis uncovered multiple perceived facilitators of implementation, for example, the rapidity of results:

> *I was able to go and give them their results before I went home, so it's great!*
>
> – Nurse
>
> *You've got the difference between getting a result you can act upon, rather than having to wait a week. So, that's a major advantage.*
>
> – Leadership

Additionally, the increased flexibility in clinic times made possible by the option of PoC testing was viewed favourably:

> *That's a good point […] because the bloods go away [are sent to the laboratory] at half past 12. So, PCR really needs to be done in the morning.*
>
> *It wouldn't have to get sent off…*
>
> *It takes away all the barriers doesn't it*
>
> *…you can extend that clinic then. Into the afternoon because you've not got that cut-off at half past 12.*

– Nurse

Perceived patient preferences, i.e. preferring capillary/fingerstick sampling to conventional phlebotomy, were seen as a facilitator to implementation, as nurses could engage individuals who were otherwise disinterested:

> *I've got one guy waiting for this machine because he refuses point-blank to get, get needles in him.*
>
> – Nurse

In addition to these key facilitators, supportive colleagues, the wider evidence base for PoC testing, and the mobility of the device were viewed as positively influential on implementing the GeneXpert in the prison.

Table 5: List of all determinants to implementation of the Cepheid GeneXpert in HMP Perth identified in semi-structured staff interviews(n=70).

Domain	Barriers (n=41)
Inner setting	Leadership staff felt individual custody trumped healthcare in the prison, hindering improvements to care.
	Laboratory staff did not prioritise uploading GeneXpert results as they did not perform the test.
	Laboratory staff did not prioritise reporting GeneXpert results because it was a pilot project.
	Leadership staff felt that, as the nurses were not present for the majority of admissions, in-reach was limited.
	Leadership staff felt a lack of freedom to operate in the prison hindered the design of the pathway.
	Clinical staff felt the lack of physical space and clinic rooms adversely affected how and when the GeneXpert could be used.
	Clinical staff were limited to using the GeneXpert and obtaining samples for testing in specific locations in the prison.
	Clinical staff found it difficult to transit individuals from residential areas of the prison the health centre due to the need for intermediary 'runners'.
	Clinical staff felt pressured by SPS staff to finish clinic appointments quickly.
	Clinical staff found it difficult to implement healthcare initiatives as it was perceived as secondary to the regimental running of the prison/security.
	Clinical staff found it difficult to engage colleagues outside their direct team in HCV testing due to perceived lack of integrated care.
	The GeneXpert was seen as difficult to implement in the long-term due to high staff turnover in the prison.
	Laboratory staff found it difficult to log results in a timely manner due to staff turnover and training issues.

Outer setting	Laboratory staff felt uncertainty around whether reporting tasks could be delegated to administrative staff due to professional regulations. Laboratory staff found it difficult to manage the reporting workflow due to the pressures of the Covid-19 pandemic.
Characteristics of Individuals	Leadership staff felt a lack of awareness of HCV among people in prison and prison staff hindered improvements to prison care. Laboratory staff did not see administration of GeneXpert results as part of their job/in line with their skillset. Laboratory staff felt uncertain about the value of their role in the reporting process. Clinical staff felt cynical about whether SPS staff 'runners' actually approached individuals to inform them their attendance at the health centre was required. Clinical staff indicated a preference to obtain a venous sample to fingerprick sample due to their self-perceived proficiency at obtaining venous bloods. Clinical staff viewed fingerprick sampling method as slower than obtaining venous samples. Clinical staff often wanted to know antibody status of an individual, meaning at times they may not have prioritised PCR testing with GeneXpert. Clinical staff felt obtaining fingerpick samples using the minivette introduced infection control concerns. Laboratory staff felt unsure about the value of their role in the result reporting process.
Intervention characteristics	Leadership staff felt the need to return to device to check result after one hour made it difficult to plan work for a clinic when they had competing priorities for their time. Performing a GeneXpert test was perceived as more work than obtaining conventional samples and sending them for lab analysis, by leadership staff. Transporting GeneXpert test assays in the prison caused anxiety for clinical staff due to the sensitivity of the rear fin on the cartridge. Clinical staff felt the dexterity required to correctly insert the sample into the cartridge caused errors in results. Laboratory and clinical staff found it challenging to interpret the viral load quantification output (scientific notation) from the device.
Process	Laboratory staff felt the lack of an IT link raised concerns about accurate result reporting. Laboratory staff found it difficult to plan/implement an SOP for reporting results, as they were unsure what to expect in terms of volume of tests. Clinical staff had difficulty conceptualising how the device would be used due to a lack of a plan on who to target for testing and how to do so. Clinical staff found it difficult to plan a 'one-day' test/treat pathway due to safety concerns with the frontline medication used. Clinical staff found it difficult to transit individuals to the prison health centre due to the provision of OAT at concurrent time to BBV clinics. The GeneXpert process was viewed as time-consuming difficult to implement systematically due to unpredictable nurse workload.

	Laboratory staff did not prioritise uploading test results to electronic systems because they did not perform the test themselves. The paper reporting process was felt to introduce potential for result reporting/transcription errors. Laboratory staff found it difficult to adapt to the paper/manual reporting workflow as it was unfamiliar to them. Laboratory staff felt there was poor communication between themselves and clinical staff implementing the testing. Clinical staff found it difficult to verify patients' CHI numbers as they are not routinely used in the prison system. Clinical staff were anxious about the paper reporting process because it placed a high degree of responsibility on them not to make reporting errors.
	Facilitators (n=29)
Inner setting	Laboratory staff were open to challenge on results incorrectly uploaded due to their perceived professional responsibility to ensure accuracy. Clinical staff found it easier to plan engagement with testing by co-designing awareness materials with people in prison. Clinical staff found it easier to implement the GeneXpert pathway because of previous testing undertaken in the prison for diabetes by another team. Clinical staff found it easier to navigate the prison environment for testing after being 'key trained'. The prison BBV nursing team's openness to change and credibility with prison staff was perceived as helpful to implementation, by leadership staff. Clinical staff found it easier to engage patients due to the ethos of their team which values individual relationships.
Outer setting	The local HCV elimination strategy was seen as facilitative of improving care by leadership staff. MCN infrastructure and inter-organisational working was seen as facilitative of improving prison BBV care by leadership staff. GeneXpert was viewed as preferable for sampling in patients with difficult venous access by clinical staff. Some people in prison indicated a preference to clinical staff to be tested using the GeneXpert due to the non-invasive sampling. Clinical staff found it easier to implement the GeneXpert pathway as the virology team were perceived as supportive.
Characteristics of Individuals	Laboratory staff felt prior experience with reference result reporting and prior PoC pilots for flu were helpful in implementing the result reporting workflow for the GeneXpert. Laboratory staff appreciated the unique testing challenges in the prison environment. Laboratory staff perceived GeneXpert testing in the prison as innovative. Wider knowledge of GeneXpert testing in other UK cities among laboratory staff and individual advocacy among those staff facilitated the decision to support the project. Clinical staff trusted the results from the GeneXpert due to an awareness other teams were using them.

	Clinical staff perceived the GeneXpert as making their job easier. New staff in the prison health centre were perceived as being open to change by existing clinical staff. Clinical staff perceived the GeneXpert as enabling quicker transition from diagnosis to treatment.
Intervention characteristics	Leadership staff felt the strong existing evidence base on the clinical effectiveness of the GeneXpert and benefits of HCV treatment for PWID facilitated implementation. Laboratory staff found it easier to integrate the GeneXpert as there were no financial implications to do so. Clinical staff found it easier plan their use of the GeneXpert as it was mobile (on trolley). Clinical staff could plan afternoon clinics/more flexible clinic times as the GeneXpert made the 12.30 bloods cut-off inapplicable for PCRs. Leadership staff felt that GeneXpert delivered quick, actionable, results and was easy to use. GeneXpert was perceived as preferable to conventional testing due to the speed of the results by leadership staff.
Process	Laboratory staff felt existing lab systems could be easily amended to integrate the GeneXpert test platform. Clinical staff found it easier to engage people in prison into testing by building rapport with and disseminating HCV information via 'pass men'. Laboratory staff felt integrating the GeneXpert process as a whole was minimally disruptive to their usual work. Laboratory staff felt it was an easier process compared to conventional testing as they did not have to process the samples themselves.

Abbreviations: HMP, Her Majesty's Prison Service; HCV, hepatitis c virus infection; IT, information technology; SOP, standard operating procedure; OAT, opioid agonist therapy; BBV, blood-borne virus; SPS, Scottish Prison Service; CHI, community health index; MCN, managed care network; PoC, point-of-care; UK, United Kingdom; PWID, people who inject drugs; PCR, polymerase chain reaction.

Discussion

Interventions to enhance transition to HCV treatment are required for critical populations, including incarcerated people, if WHO 2030 elimination goals are to be realised.[28,29] This single-site evaluation has demonstrated that it is clinically beneficial to implement on-site nurse-led PoC RNA testing for HCV in a maximum-security Scottish prison. One-hundred and sixty-seven PoC tests were administered and, among individuals who tested HCV positive, those who received one had increased likelihood of initiating treatment sooner than those tested conventionally. This effect was observed in both the main models and simplified supplementary models, though the magnitude of the effect is likely most realistic in model one reported here (19 vs 33 days; *a*HR 1.91 [1.03–3.55]), which compared PoC testing to

conventional service delivery unincumbered by the effects of COVID-19. However, the proportion of error/invalid tests in our pilot was higher than observed in other real-world settings. For example, an Australian study implemented PoC RNA testing in needle and syringe provision (NSP) sites, where testing was undertaken by non-healthcare staff.[30] In this study, 1.4% (2/140) of all PoC RNA tests were invalid. Another study implemented the same intervention across harm reduction centres in Georgia.[31] The error rate was slightly higher in this study at 3.6% (22/619) – and most were related to operator error, similar to our findings – but still much lower than the rate in our evaluation. The number of failed tests did attenuate over time (Figure S2), which suggests an association with operator proficiency (i.e. a learning curve).

As noted in the qualitative results, staff turnover was an issue in this pilot, which is common in prison health services.[32] This may have impacted upon Xpert® error rates. The laboratory services also experience high staff turnover and difficulties managing the reporting workflow due to Covid-19 (Table 5). This somewhat explains the proportion of result reporting inaccuracies which occurred, particularly the spike in June 2020 (Figure S3) and the following months as services remobilised following the initial covid outbreak. Ensuring prompt and adequate training for new staff will be critical to reducing the likelihood of errors going forward.

The cost analysis suggested that employing this PoC RNA an approach may not be cost favourable. Price differences appeared to be impacted by: a) the significant difference in linkage-to-treatment for the GeneXpert group relative to the conventional group in the pilot phase, which incurred higher treatment costs; b) the proportion of RNA tests in the pilot phase which were Xpert® rather than conventional, meaning higher overall testing costs, despite the lower cost-per-test at the individual level; and c) LTFU among those who started treatment, which was proportionally higher in the GeneXpert group (5/16; 38%), relative to those conventionally tested in pre-pilot (7/33; 21%) and pilot (0/11; 0%) phases. Improved linkage-to-treatment is important to consider when choosing whether to implement such

interventions because, with the high efficacy of DAA treatment, LTFU individuals are likely to have achieved SVR.[12] The costs of a relatively less efficient pathway may be higher with respect to enduring HCV transmission and its attendant consequences. In the hypothesised scenario of maximum discounting of DAAs, and cure attainment among those LTFU, the GeneXpert group costs became favourable relative to the pre-pilot phase. For others considering a similar approach, consideration might be given to this, as well as the identified implementation determinants.

Bringing quickly actionable HCV testing closer to incarcerated people has been increasingly advocated in recent years.[33–35] The primary results reported here align with recent similar research. A study undertaken in HMP Wormwood Scrubs, England, reduced time from screening to treatment from three months, for those tested by DBS, to one week, by implementing PoC RNA testing and augmenting it with a streamlined care pathway.[36] However, processing of GeneXpert samples was not undertaken on site. Similarly, an Australian study reported high test uptake and shortened transition to treatment among a cohort screened upon reception using a one-stop approach including PoC RNA testing with additional fast-track components. Initial results indicated those tested by PoC had shorter time from testing to treatment (6 v 90 days; $p<0.001$) as well as high treatment uptake, similar to our findings.[37] Although views of imprisoned people on the acceptability of PoC testing did not form part of the work undertaken here, other studies have examined this. A qualitative sub-study on the Australian project showed the PoC intervention was highly acceptable to participants.[38] Other work found testing in this manner highly acceptable, with most preferring it to venepuncture.[39] Further, a Canadian study found PoC fingerprick HCV testing was highly preferred to conventional venepuncture for those with challenging venous access, which we also observed in the qualitative analysis.[40]

Currently we know what works well for HCV diagnosis and treatment on a technical level.[41] Therefore, we have reported multiple determinants of implementation with the intention of informing projects undertaken elsewhere (Table 5). Overall, the results implied an underlying

tension between individual knowledge, self-efficacy, and organisational culture, with leadership, readiness to implement, and prioritisation of work. In the *inner setting*, most barriers were associated with the constrained nature in which clinical staff could operate within the prison; the relative priority of healthcare in the prison environment; staff turnover and training issues; and the relative priority of the pilot to laboratory staff. Most facilitators were in the *characteristics of individuals* domain. They predominantly spanned existing knowledge of the GeneXpert platform; prior experience with PoC testing for other clinical indications; a perception of the GeneXpert as innovative and easing workloads; and a perceived openness to change among nursing staff. In *intervention characteristics*, staff felt the need to return to the device after 60 minutes to conclude the process was inconvenient relative to conventional methods. Further, the sensitivity of the assays to external forces; the way the device reports viral load quantification; and obtaining fingerprick samples were all observed as challenges.

Conversely, the evidence around the GeneXpert; the mobility of the device; its impact on clinic planning; and the rapidity of test results were all positive influences. In the *process* domain, the result reporting procedure, although effective, was less attractive than an automated electronic system. Of the PoC tests with some level of inaccurate information on electronic health records (Table S2, Figure S3), most, if not all, could have been avoided with an automated electronic result reporting system. Other programs integrating PoC RNA testing into routine BBV care should give serious consideration to developing such a link. Finally, in the *outer setting*, professional regulations made it difficult to delegate certain tasks to alternative staff members, and impacts related to COVID-19 made the reporting workflow challenging to manage within the laboratory. Overall, in the wider regional context, the HCV elimination strategy in Tayside, along with the organisational structures which govern it, were seen as facilitative. We hope that by reporting the determinants of implementation against a recognised transferrable framework, we can increase their relevance across divergent settings and contribute to program design elsewhere.

This evaluation has multiple limitations. We did not seek the views of patients on the acceptability of PoC RNA testing, due to the nature of the work which was focused primarily on implementation from a health systems perspective and inherently limited in scope. Beyond this, the qualitative analysis used convenience sampling, which is non-random and prone to motivation bias and limited generalisability.[42] Determinants reported here may thus not be representative of other jurisdictions that have run similar projects, and future comparative studies would be valuable to determine this when the literature base is more robust. Additionally, in the qualitative work, diverging interview methods were used (focus group and one-to-one), with attendant strengths and weaknesses. The focus group approach, for example, could have led to hesitance in expressing views in the presence of staff of differing seniority, minimal expression of deviating opinions, limited discussion due to confidentiality or disclosure issues, or bias from moderator intervention.[43,44] Conversely, individual interviews may have generated interviewee self-consciousness; lacked the spontaneity of group discussion; and struggled to describe the commonness of issues raised.[45] These biases and issues will inherently have affected the quality of data. All interviews may have been biased by interviewee familiarity with the interviewer/facilitator, and the interviewer's existing knowledge of the intervention. Further, the sample who participated in qualitative interviews was limited – almost all relevant staff (nurses, biomedical staff, service leadership, commissioning staff) participated – but may raise concerns regarding 'saturation'. With respect to this, given the specialised knowledge of participants; their relevance to the pathway; the use of an established theoretical framework; and a pre-specified analysis strategy, the concept of 'information power' is relevant.[46] This suggests the more information a sample holds, relevant to the evaluation, and where scrutiny is informed by a theoretical framework, the fewer participants are required to 'saturate' the analysis. In taking an approach conceptually aligned with this view, we hoped to ameliorate some of the challenges associated with the qualitative strand of the evaluation. Other limitations include the impact of COVID-19 on laboratory testing turnaround times during the pilot, which may have disadvantaged the conventional group in the survival

analysis, and the rudimentary approach to the cost analysis, which only included direct costs. Finally, the survival data frame was right censored for some cases, meaning their exact survival time was uncertain.

Conclusions

The results suggest that integrating the Cepheid GeneXpert platform into routine nurse-led HCV care in a maximum-security prison health centre improves linkage to treatment in the Scottish context. Our data augments the available literature with respect to the benefits of this approach on linkage to care, but reports gains which are more modest, possibly driven by the absence of additional care pathway changes reported by others. Multiple determinants to implementation were highlighted, which may inform similar pilots in other prisons. The new platform was less favourable in cost terms than conventional testing; however, this was affected by several factors (linkage to treatment, LTFU), and in realistic hypothesised scenarios multiple favourable cost outcomes were observed. Consequent of this pilot, we are now undertaking further research informed by this work with this testing platform in local NSP sites, and a comparable analysis is planned.

Appendices

Author contributions

CJB, SKI, and JFD conceptualised the evaluation. CJB curated data; selected the methodologies employed; undertook qualitative and quantitative analyses; visualised data; and wrote the original draft. SKI and JFD provided supervision. AM undertook qualitative data analysis. All authors contributed to revisions and approved the final version of the manuscript. CJB had full access to the data and takes responsibility for the integrity of the data and the accuracy of analysis.

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Cepheid UK Ltd provided diagnostic platforms and test assays free-of-charge and provided funding for a fixed-term part-time coordinator to facilitate the pilot. Cepheid UK Ltd played no role in design of the evaluation; data collection, analysis, or interpretation; the writing of the manuscript; or the decision to submit the manuscript for publication. Award number: N/A.

Competing interests

CJB, AM, and SKI, have no disclosures. JFD reports grants and personal fees from AbbVie; grants and personal fees from Gilead; and grants and personal fees from MSD, outside the submitted work.

Patient and public involvement

Patients and members of the public were not involved in the design or conduct of this work.

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Data availability statement

Quantitative data underpinning this study were obtained from routinely updated NHS health records in line with approval granted by the NHS Caldicott Guardian. The individuals to whom the data pertains did not explicitly consent to its use for research purposes. Therefore,

it is not possible for the authors to share this data. However, interested parties can make specific requests to NHS Tayside Information Governance by email on: informationgovernance.tayside@nhs.scot. Consideration will be given to sharing qualitative data upon receipt of a methodologically sound proposal and will be subject to the agreement of interview participants.

Ethics Approval

As this was a retrospective service evaluation, NHS ethical review was not required. Instead, Caldicott Guardian approval was obtained for data access (IGTCAL7004). This process reviews internal NHS evaluations, ensuring the protection and appropriate use of patient data. The evaluation was also registered with the NHS Tayside clinical governance group for prison healthcare (ref: 27/19).

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Figure legends

Figure 1: Summary of observation dates and study activities.

Note: Conventional testing was by whole blood sent to a laboratory for analysis and dried blood spot methods.

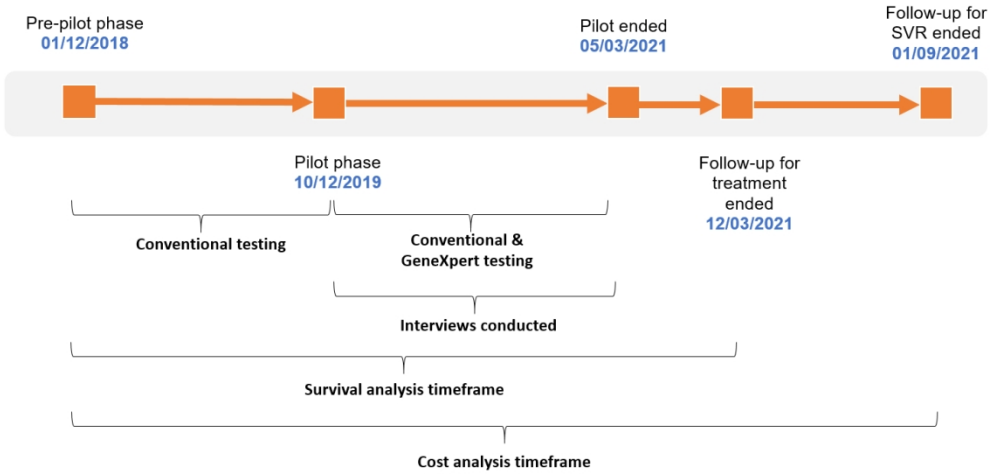
Figure 2: Target cohort profile with related clinical outcomes and censoring.

*Cases received treatment but excluded from cost and time-to-treatment analyses, as their testing data was unavailable or unverifiable.

†All censored in survival analysis at relevant decease, liberation, transfer, or follow-up censor dates.

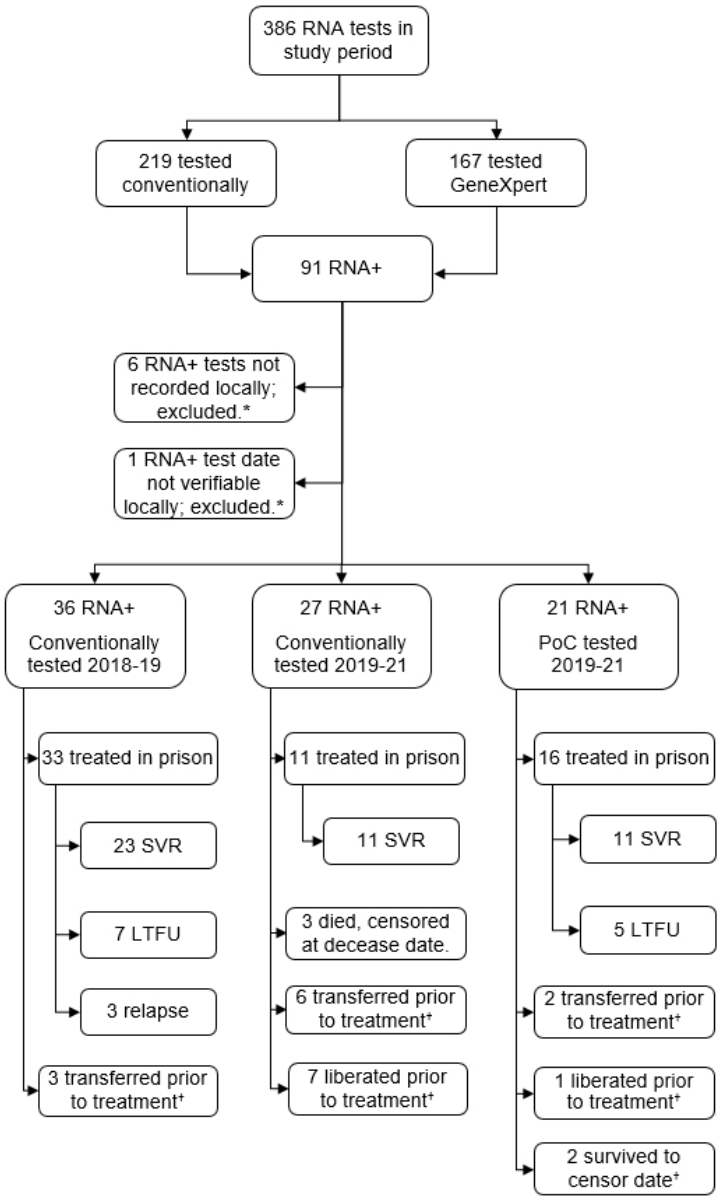
Notes: Group 1 are those tested conventionally from 2018-19 (reference period); group 2 are those conventionally tested during the pilot phase (2019-21); group 3 are those tested with the GeneXpert during the pilot phase (2019-21).

Abbreviations: RNA, ribonucleic acid; RNA+, ribonucleic acid positive (actively infected); PoC, point of care; SVR, sustained virologic response; LTFU; lost to follow up.



Summary of observation dates and study activities.

971x468mm (38 x 38 DPI)



Target cohort profile with related clinical outcomes and censoring.

349x573mm (38 x 38 DPI)

Appendix S1

A mixed-methods evaluation of point-of-care hepatitis c virus RNA testing in a Scottish Prison.

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Table S1: Proportional hazards models stratified by test type (n=84).

	Variable	n (%)	HR (95%CI)	*p*
Model 1	Conventionally tested (ref)	63 (75.0)	…	
	GeneXpert tested	21 (25.0)	2.52 (1.40–4.52)	.002
	Variable	**n (%)**	***a*HR (95%CI)**	***p***
Model 2	Conventionally tested (ref)	63 (75.0)	…	
	GeneXpert tested	21 (25.0)	3.54 (1.41–4.59)	.002
	Age at test	…	1.03 (0.99–1.07)	.103

Abbreviations: PH, Proportional hazards; aHR, adjusted hazard ratio; CI, confidence interval.
Model 1 fit: X^2=8.23, p=0.004. Harrell's C: 0.63 (95% CI 0.56-0.70), p = <.0001.
Model 2 fit: X^2=10.86, p=0.004. Harrell's C: 0.63 (95% CI 0.55-0.72), p = <.0001.
Survival information both models: failures = 60; time at risk = 4,719 days.
Note: Unadjusted (model 1) and age-adjusted (model 2) proportional hazards models with cases grouped depending on which HCV test they received during the pilot (conventional phlebotomy/dried blood spot or point-of-care using the Xpert fingerstick assay).

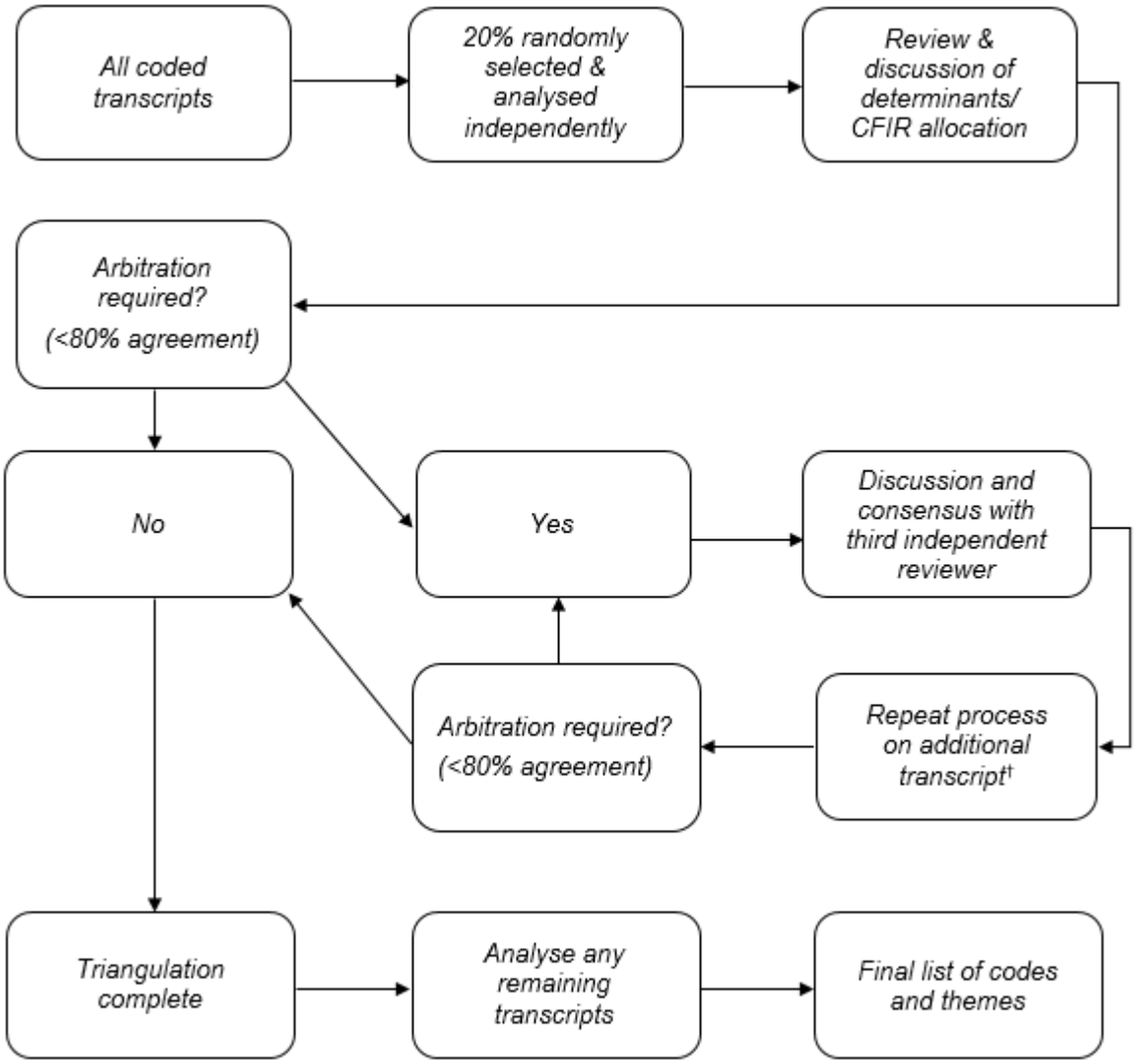

Figure S1: Pre-specified qualitative triangulation algorithm.
†If no transcripts remaining, triangulation is complete.

Table S2: Point-of-care test result reporting errors.

Issue encountered	n
Test not reported on ICE	16
ICE report states sample type oral fluid	7
Test reported on ICE, result not specified	2
ICE report specifies inaccurate result	1
ICE report specifies inaccurate test date	2
Total	28

Abbreviations: HMP, His Majesty's Prison service; ICE, integrated clinical environment.
Note: ICE is the local electronic health record system for recording clinical tests administered to patients.

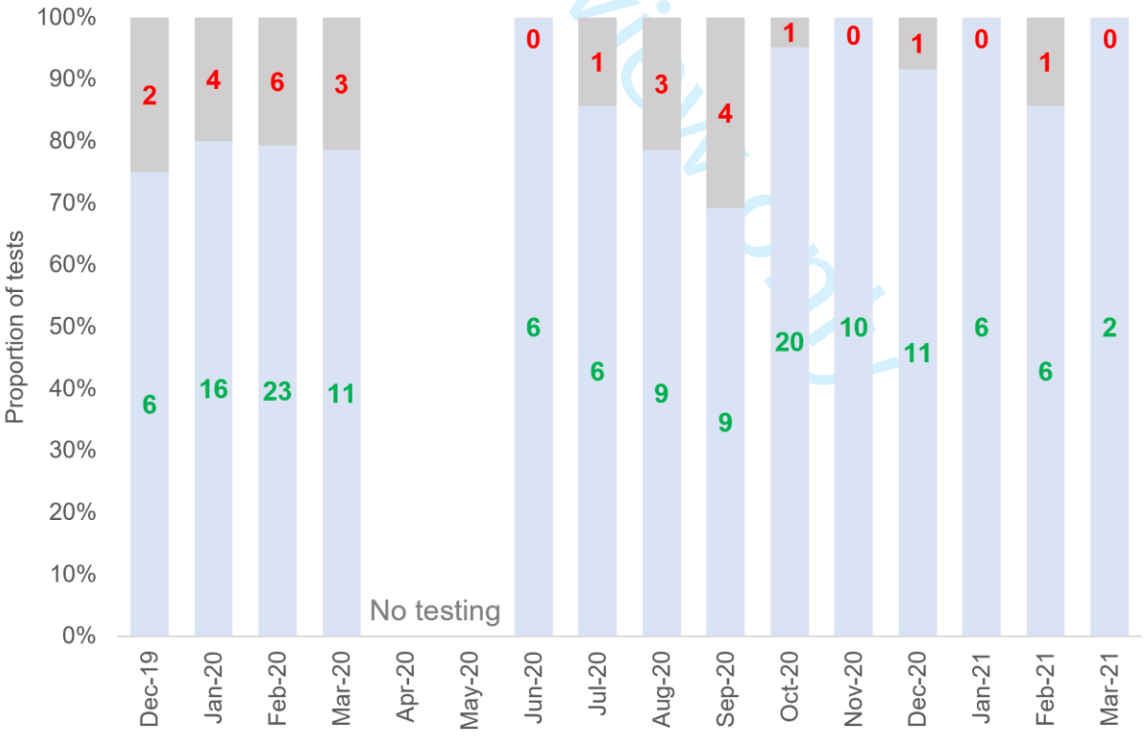

Figure S2: Number of completed (in green) and failed (in red) Xpert® Fingerstick RNA tests per month demonstrating a proportionate decrease over time.
Note: Failed tests include both ERROR (n=23), which were operator related, and INVALID (n=3), which were not operator related, results.

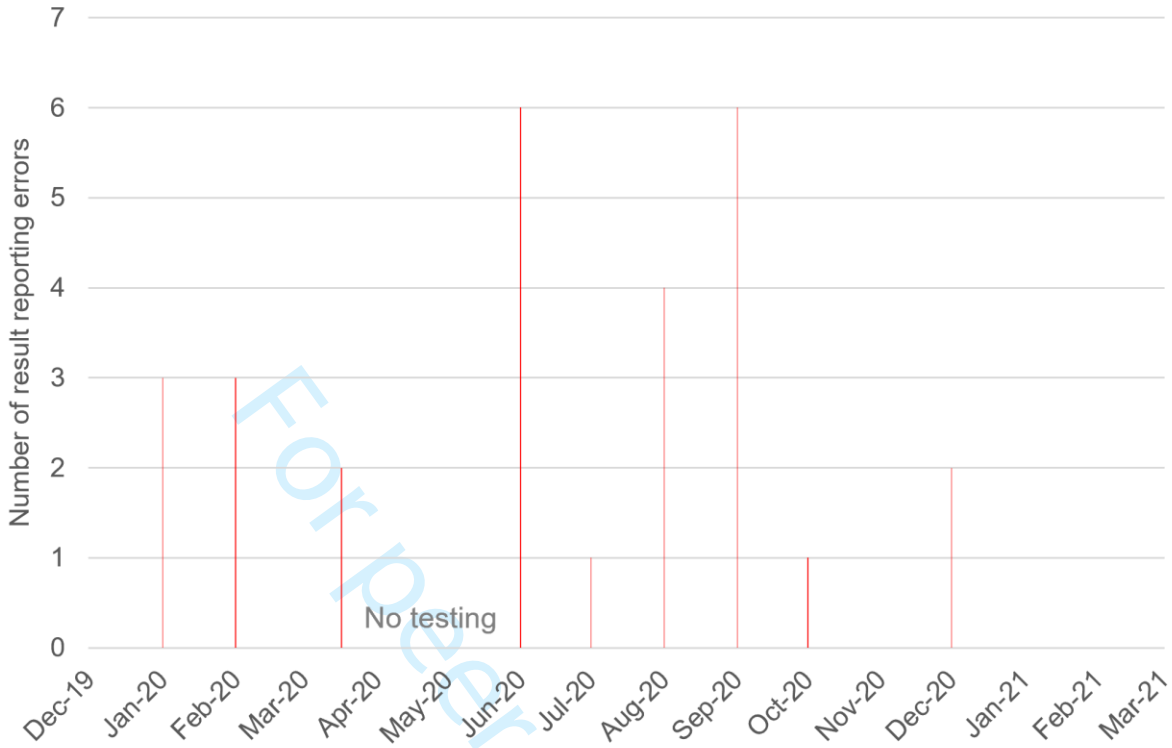

Figure S3: Number of Xpert® Fingerstick RNA test result reporting errors over time.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	PAGE
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5-6
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6-9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-9
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	7-8
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-10
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	7-8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8-9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9
		(*b*) Describe any methods used to examine subgroups and interactions	8-9
		(*c*) Explain how missing data were addressed	8-9
		(*d*) If applicable, explain how loss to follow-up was addressed	8-9
		(*e*) Describe any sensitivity analyses	…
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	10
		(c) Consider use of a flow diagram	Fig 2
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10; table 1
		(b) Indicate number of participants with missing data for each variable of interest	10-11; Fig 2
		(c) Summarise follow-up time (eg, average and total amount)	10; 12; table 2
Outcome data	15*	Report numbers of outcome events or summary measures over time	10-12
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted	10-12;

		estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	table 2
		(*b*) Report category boundaries when continuous variables were categorized	…
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	…
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	13-19
Discussion			
Key results	18	Summarise key results with reference to study objectives	19-20
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	23-24
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	24
Generalisability	21	Discuss the generalisability (external validity) of the study results	4; 23
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	25

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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Title

A mixed-methods evaluation of point-of-care hepatitis c virus RNA testing in a Scottish prison.

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Abstract

Objectives

Hepatitis C Virus (HCV) poses a global public health threat. Prisons are a focus of prevention efforts due to high infection burdens. Expedition of treatment for incarcerated people is critical, as many are short-term sentenced. We evaluated point-of-care (PoC) HCV RNA testing in a maximum-security Scottish prison and assessed its impact on transition to treatment. We also evaluated costs and determinants of implementation.

Design

Mixed-methods evaluation of a single-centre care pathway pilot using NHS service data from 2018-21. Descriptive statistics and survival analysis were undertaken. Cost analysis was assessed from a provider perspective. Healthcare staff participated in semi-structured interviews and thematic analysis with a deductive approach was undertaken to identify implementation determinants.

Setting

A large maximum-security Scottish prison health centre administered by the NHS.

Participants

296 incarcerated NHS patients (all male) and six NHS staff members (two male, four female).

Interventions

Hepatitis C Virus (HCV) testing using the Cepheid GeneXpert platform with Xpert® HCV VL Fingerstick assay.

Outcome measures

The main outcome was survival (in days) from HCV test to treatment initiation. Secondary outcomes were cost-per-cure obtained and implementation determinants.

Results

During the pilot, 167 Xpert® tests were administered, with an 84% completion rate, and treatment transition was superior for those who received it (*p*=.014). Where PoC tests were administered, shorter survival to treatment was observed (19 vs 33 days: *a*HR 1.91 [1.03-3.55], *p*=.040; 19 vs 50 days; *a*HR 3.76 [1.67-8.46], *p*=.001). PoC was costlier than conventional testing. In qualitative analysis, most facilitators were observed among characteristics of individuals domain whilst most barriers were noted in the inner setting.

Conclusions

Integrating PoC HCV RNA diagnosis into nurse-led HCV care in a maximum-security prison health centre shortens survival to HCV treatment. However, there are cost implications to this approach and multiple determinants that impact upon implementation should be addressed.

Strengths and Limitations of this study

- The study is strengthened by assessing the feasibility of point-of-care (PoC) testing from multiple angles which address clinical impact, costs to the health service, and barriers and facilitators to implementation, giving a holistic view of this approach.
- In contrast to other similar work, a strength of this study is that PoC testing was administered by nurses in the prison health centre.
- The study is limited by a small sample in the qualitative component, and its single-centre nature, which both restrict the generalisability of the findings.
- The study is further limited by only including NHS staff in the qualitative component.

Introduction

Hepatitis C Virus (HCV) infection is an enduring global public health threat. For those infected, in the absence of diagnosis and linkage to treatment, it can cause long-term negative health outcomes, such as progression of liver fibrosis to eventual cirrhosis, decreased health-related quality of life, and extra-hepatic sequelae such as renal or cardiovascular impairment. Prisons have been an important focus of HCV prevention efforts due to their high HCV burden relative to the general population, which intersects with the large number of people who inject drugs (PWID) who are imprisoned.[1] Imprisonment rates among PWID are substantial, with up to 58% estimated to have ever been incarcerated.[2] Further figures suggest that up to 38% of incarcerated people may have been exposed to HCV, due to the overlapping nature of injection drug use (IDU) and incarceration, and the absence of primary prevention measures for PWID whilst incarcerated.[3,4] Sharing of non-sterile injecting equipment in prisons is the leading cause of HCV transmission.[2] A previous study of Scottish prisons found that 32% of people in prison had a history of IDU and, among those, HCV prevalence was 53%.[5]

Recent data indicate that approximately 71% of individuals test positive for illicit substances upon reception to Scottish prisons; of those, 29% test positive for opioids and 24% for cocaine, which are commonly injected.[6] In the prison in this evaluation, approximately 38% and 18% of individuals tested positive for these respectively upon reception, implying an ongoing risk of blood-borne virus (BBV) transmission.[6] The Scottish justice system has a 'remand problem', defined as imprisonment awaiting sentence for 40-140 days.[7,8] In recent data, which spans the pilot period of this project, those identified as being in the part-year prison population across the prison estate, i.e. residing in a given establishment for less than one whole year, was estimated at 80.2%.[9] Recent figures for His Majesty's Prison (HMP) Perth, the prison in this pilot, estimated the remand population at approximately 22.8%.[10] These figures suggest substantial proportions of the prison population are highly transient, at risk of HCV transmission, with a short time-frame for healthcare engagement.

In the context of HCV, expedition of treatment for incarcerated persons is important to avoid loss to the system. Treating HCV-infected individuals whilst incarcerated has been identified as an important engagement strategy for people otherwise disconnected from conventional healthcare.[11] HCV treatment duration is relatively fixed, which leaves diagnosis as the key remaining modifiable care component.[12] Particularly in the absence of enhanced harm reduction supports to reduce risk, which are scarcely available in prisons.[13] This is especially pertinent to Tayside because Dundee, whose population is served by the prison in this evaluation, has the highest rate of incarceration per head of population in Scotland, as well as a historically high burden of HCV infection.[9,14] Consequent to this historically high HCV burden, Tayside has a suite of well-developed community care pathways which offer HCV care from multiple environments. Those affected by BBVs, such as HCV, who are liberated from HMP Perth to the local area are appointed to nurse-led community outreach clinics or local pharmacies for treatment continuation or post-treatment follow up after liberation.

In recent years, point-of-care (PoC) HCV testing platforms have become available which could ameliorate time burdens associated with existing testing methods and streamline linkage to treatment. However, the evidence documenting the impact these devices have in real-world prison contexts is nascent. Further, the determinants to integrating PoC testing for HCV RNA into prison environments are unclear and there has been limited examinations of the cost implications of such interventions in UK prisons. This manuscript describes a pilot project in a Scottish prison which integrated PoC HCV RNA testing into routine on-site nurse-led care using the Cepheid GeneXpert platform with the Xpert® HCV VL Fingerstick assay.[15] The primary outcome of this study was to determine if there was a difference in survival, measured in days, from a positive HCV RNA result and treatment initiation, among those who received a PoC test relative to those tested conventionally. Secondary outcomes were to: assess the cost of PoC RNA testing relative to conventional methods; and evaluate the determinants to implementing the PoC RNA testing platform.

Methods

Study design

This was a mixed-methods NHS service evaluation – with retrospective analysis of routine NHS HCV testing, treatment, and cost data, and prospective qualitative interviews – of a modified HCV care pathway in HMP Perth, a prison in central Scotland.[16,17] Accordingly, no randomisation, masking, or allocation to alternating interventions were undertaken as part of this pilot (choice of test rested with practitioner/patient). Caldicott Guardian approval was granted for data access (IGTCAL7004).[18] This process reviews internal NHS evaluations, ensuring the protection and appropriate use of patient data The evaluation was registered with the NHS clinical governance group for prison healthcare (ref: 27/19).

Patient and public involvement

Patients and members of the public were not involved in the design or conduct of this work.

Setting

NHS Tayside is a large health board are located on the East of Scotland. HMP Perth is a large maximum-security male prison in the NHS Tayside board area which houses people on mixed-duration sentences.[19] Healthcare is provided by the NHS from an on-site centre. Opt-out HCV testing is in place on reception to prison and includes conventional phlebotomy and dried blood spot (DBS) methods.[20] Prison staff escort individuals from the residential areas of the prison to BBV clinics. As a test of change, PoC HCV RNA testing was integrated into routine care in prison BBV clinics alongside conventional testing methods.

Participants

This study used existing service data for quantitative analysis. All adults (≥18 years) with detectable HCV RNA, and/or treated for HCV in HMP Perth from December 2018 to March 2021 were eligible for inclusion. The timeline for the study is shown in Figure 1. Data was collected for a one year ‘pre-pilot’ phase, when only conventional testing was offered, to compare against the pilot phase data. In the analysis, those tested during the pilot phase were grouped by whether they received a PoC test or a conventional test, for comparison.

NHS Tayside staff members involved in any stage of the implementation process were eligible to participate in the prospective qualitative strand.

[Figure 1]

Clinical outcomes

Clinical outcomes were collected to inform the cost analysis. SVR was undetectable (<10 IU/mL) HCV RNA at least 12 weeks post-treatment. Relapse was undetectable RNA at end of treatment, but detectable prior to or at SVR; or treatment initiation and detectable RNA prior to or at SVR, if end of treatment test not conducted. Loss to follow up (LTFU) was defined as no post-treatment RNA test on record up to and including the censor date.

Statistics

Descriptive statistics were undertaken to obtain relevant counts and proportions. To assess the primary outcome, individuals were grouped depending on their test type (conventional or PoC) and when the test was taken (pre-pilot or during the pilot). Kaplan-Meier failure analysis and log-rank testing were undertaken, followed by Cox proportional hazards (PH) modelling. Two PH models were fit: one comparing the PoC group to the pre-pilot conventionally tested group; and one comparing the PoC group to those tested conventionally during the pilot. This strategy was chosen for two reasons: 1) to account for any changes to service delivery beyond our control during the pilot period (for example anything implemented by the prison service), and 2) the COVID-19 pandemic occurred during the pilot, which impacted upon laboratory test turnaround times. We sought to ensure any effect observed was independent of this lag. Models were also adjusted for age, as a proxy for potential transience through the prison (in the absence of sentencing data, and based on the experience of the project team). Limited models were also performed (Table S1 [Appendix S1]) with straightforward comparisons based on test type alone. The terminating event was treatment initiation. To assess treatment opportunity loss during the pilot, equality of proportions who remained untreated between groups were tested using a

two-sample test of proportions (*z* test). Statistical testing was undertaken using Stata BE 17. *P* values of ≤0.05 were assumed to demonstrate statistical significance.

Cost analysis

Although healthcare cost analyses typically express outcomes in quality-adjusted life years and willingness-to-pay thresholds,[21] it was not possible to collect the data for this type of analysis in this retrospective evaluation. Consequently, an incremental 'cost-per-SVR' approach was taken from an NHS perspective, where the costs of all HCV RNA test and treatment were summed and divided by the population benefits of linkage to care, i.e. obtaining SVR. Costs for all relevant sample types were obtained from the manufacturer or NHS department. Medication costs were estimated from the British National Formulary and published sources, and do not account for discounting in the primary calculations.[22-24] Staff time was costed proportionately in line with NHS agenda for change.[25] Estimates do not include sundry items and do not account for inflation. Those whose pre-treatment HCV RNA test could not be verified were excluded. The time horizon was the study period.

Qualitative methods

A convenience sample of NHS staff members (n=8) known to the research team, and involved in implementing the GeneXpert, were invited to participate in semi-structured interviews. Written informed consent was obtained. For practical reasons, focus groups were undertaken with nursing staff, while individual interviews were undertaken with others. These were recorded digitally and transcribed verbatim with identifying data censored. The Consolidated Framework for Implementation Research (CFIR) informed interview guide design and data analysis.[26] The interview guides are included in Appendix S1 (Tables S2–S5). The CFIR is a meta typology composed of five major domains, which provides a structured and pragmatic approach for understanding real-world implementation initiatives.[26] It was selected for its systems-level approach, consistent with the NHS analytic perspective. Non-NHS staff and prison residents were not approached to participate as they were outwith the remit of NHS service evaluation.

Thematic analysis was undertaken to analyse interview data using a deductive approach.[27] Transcripts were read two times by the analyst (CJB) and coded for 'barrier' or 'facilitator'. A barrier was defined as any phenomenon that had an inferred negative impact on any aspect of implementation, real or abstract, conversely a facilitator was any phenomenon inferred to have had a positive impact. Once compiled, determinants were allocated to domains of the CFIR. Triangulation of determinants was performed on 20% of transcripts by an independent analyst (AM) according to a pre-determined algorithm (Figure S1, [Appendix S1]). Divergences were discussed until consensus was reached and this informed coding of remaining transcripts. Analysis was on screen or paper, without use of analytic software.

Results

Primary outcomes

From December 2018 to March 2021 (Figure 1), 386 RNA tests were performed, which identified 91 (23.6%) RNA-positive cases requiring treatment. Of those 91, 70 (76.9%) were tested conventionally and 21 (23.1%) with the GeneXpert. Sixty-seven (73.6%) individuals started HCV treatment. Of those, seven (10.4%) had missing or unreliable testing data and were excluded, giving a total of 60 (89.6%) treated cases for the primary analysis. In total, 167 (43.3%) RNA tests conducted were administered using the Xpert® HCV VL Fingerstick assay. Of all Xpert® tests, 23 (13.8%) returned error and three (1.8%) returned invalid results, giving an overall test completion rate of 84.4%. The 26 failed tests occurred among 20 patients. Of those, 15 patients had evidence of re-testing using the GeneXpert, consuming 18 Xpert® assays (repeat errors), whilst five had conventional blood draw. Generally, the quantity of failed tests decreased over time (Figure S2 [Appendix S1]). Error rates for conventional tests were not recorded on routine systems and therefore are unreported. Xpert® test failures were mostly related to manual handling of assay cartridges (n=24; 92.3%). Sixteen (9.6%) Xpert® tests were not recorded on electronic health records at the end of the pilot, while 12 (7.2%) had some level of inaccurate information (Table S6 [Appendix S1]) on the electronic report. This most frequently occurred when testing was re-

initiated following a short pause on clinical activities triggered by initial COVID-19 pandemic (Figure S3 [Appendix S1]).

Descriptive parameters for the analysed cohort who initiated treatment (n=60) are outlined in Table 1. Median age was 39 years, and most (70%) cases were HCV treatment naïve. The most frequent infection risk factor was IDU (91.7%). Most (60%) were in receipt of opioid agonist therapy (OAT), and there were no instances of diagnosed cirrhosis. The most common genotype was one (38.3%), followed by three (26.7%).

Table 1: Demographic and clinical characteristics of treated cases included in time-to-event analysis, 2018-21, HMP Perth, Tayside (n=60).

Parameter	Treated cases (n=60)
Gender – n (%)	
Male	60 (100)
Female	0 (0.0)
Age at RNA test – median (IQR)	39 (33.5-43.5)
Infection risk factor – n (%)	
IDU	55 (91.7)
Unknown	5 (8.3)
HCV genotype – n (%)	
1	23 (38.3)
2	1 (1.7)
3	16 (26.7)
unknown	20 (33.3)
Prior HCV treatment – n (%)	
No	42 (70.0)
Yes	18 (30.0)
OAT – n (%)	
No	24 (40.0)
Yes	36 (60.0)
Fibroscan (KpA) – median (IQR) †	5.7 (4.9-7.5)
Fib4 score – median (IQR) ‡	0.90 (0.54-1.34)
Cirrhosis diagnosis§– n (%)	
No	60 (100.0)
Yes	0 (0.0)

Abbreviations: HMP, Her Majesty's Prison; RNA, ribonucleic acid; IDU, injection drug use; HCV, hepatitis c virus; OAT, opioid agonist therapy; KpA, kilopascals; IQR, interquartile range.
†n=9
‡n=52

§Cases with Fib4 score ≤1.45 were assumed not have cirrhosis; for cases in the indeterminate Fib4 range, or cases with a score of ≥3.25, medical notes were manually reviewed to check for a diagnosis of cirrhosis by other means. Where Fib4 was not available, but Fibroscan was available, a score of ≥14kPa (F4) was used to define presence of cirrhosis, scores of <14kPa were assumed not to have cirrhosis. Cases with no assessments for liver stiffness (n=6) who commenced treatment with a standard duration (8 weeks) were assumed not to have cirrhosis.

Time to treatment was 33 (IQR 22-70) days for those conventionally tested from 2018-19; 50 (IQR 33-220) days for those tested conventionally during the pilot phase; and 19 (IQR 7-28) days for those tested using the GeneXpert during the pilot. These differences were statistically significant (X^2=13.10, p=.001). During the pilot phase specifically, 16 of 27 (59.3% [95%CI 40.7–77.8]) HCV RNA+ cases tested conventionally did not initiate treatment. Among those tested using the Xpert® assay, five of 21 (23.8% [95%CI 5.59–42.0]) did not initiate treatment. This translated to a proportionate difference in loss to treatment of 35.5% (95%CI 9.46–61.43) which was statistically significant (z=2.47, p=.014). Clinical and other outcomes are shown in Figure 2.

[Figure 2]

PH modelling, adjusted for age, is shown in Table 2. Consistent with the shorter survival time observed, the hazard of treatment was higher for those tested with the GeneXpert in both models, with a higher hazard observed when comparing cases in the pilot phase directly (model 2).

Table 2: Proportional hazards models adjusted by age.

	Variable	n (%)	aHR (95%CI)	*p*
Model 1	Conventionally tested 2018-19 (ref)	36 (63.2)	…	
	GeneXpert tested 2019-21	21 (36.8)	1.91 (1.03–3.55)	.040
	Age at test	…	1.04 (1.00–1.08)	.051
Model 2	Conventional testing 2019-21 (ref)	27 (56.2)	…	
	GeneXpert tested 2019-21	21 (43.8)	3.76 (1.67–8.46)	.001
	Age at test	…	1.02 (0.97–1.09)	.396

Abbreviations: PH, Proportional hazards; aHR, adjusted hazard ratio; CI, confidence interval.
Model 1 fit: X^2=8.07, p=0.017. Harrell's C: 0.64 (95% CI 0.56-0.72), p = <.0001.
Model 1 survival information: n = 57; failures = 49; time at risk = 2,827 days.
Model 2 fit: X^2=10.93, p=0.004. Harrell's C: 0.68 (95% CI 0.58-0.78), p = <.0001.
Model 2 survival information: n = 48; failures = 27; time at risk = 2,458 days.

Secondary outcomes

In the cost analysis, the price per SVR was higher (Table 3) for those tested with the GeneXpert relative to conventional methods in both the pre-pilot phase (+£721.30, +1.9%) and the pilot phase (+£14,499.80, +60.7%). However, when maximum discount rates were applied to medication costs, and those who were LTFU post treatment were assumed to have achieved an SVR,[12] PoC testing costs became favourable per SVR achieved relative to the pre-pilot phase (-£148.51, -4.7%). That said, in this scenario, it remained unfavourable relative to conventional testing in the pilot phase (+£372.39, +14.1%). Re-testing with the Xpert® assay, following a failed test, contributed roughly £717 of additional cost.

Table 3: Incremental cost per cure over duration of study observation period by diagnostic test type and study phase.

Parameter	Conventional (2018-19)	Conventional (2019-21)	GeneXpert (2019-21)
RNA tests (n)	164†	55†	167
Testing‡	£9,140.61	£3,078.84	£6,656.62
Actual cost per test	£55.74	£55.98	£39.86
Medication§	£857,559.78¶	£259,866.60#	£415,786.56††
Total costs	£866,700.39	£262,945.44	£422,443.18
Total SVR (n)	23	11	11
Proportion tests, SVR	14%	20%	7%
Cost per SVR	£37,682.63	£23,904.13	£38,403.93
Discounted medication rates			
Per SVR/30% discount	£26,497.06	£16,816.86	£27,064.29
Per SVR/50% discount	£19,040.02	£12,092.01	£19,504.54
Per SVR/90% discount	£3,728.52	£2,642.32	£4,385.03
Discounted medication rates, all LTFU assumed cured			
Per SVR/0% discount	£28,890.01	£23,904.13	£26,402.70
Per SVR/30% discount	£20,314.42	£16,816.86	£18,606.70
Per SVR/50% discount	£14,597.35	£12,092.01	£13,034.37
Per SVR/90% discount	£3,163.22	£2,642.32	£3,014.71

†213 venepuncture samples and 6 dried blood spot samples sent for RNA testing.
‡Combined costs for RNA samples. Note that the cost per test was calculated by dividing the testing costs by the number of tests performed in each group.
§Combined costs at full list prices, estimated from British National Formulary online, and does not include any negotiated discounts.
¶Glecaprevir/pibrentasvir, 100/40mg at £12,993.66 per pack of 84, 8-week duration (n=32); sofosbuvir/ledipasvir 90/400mg at £12,993.33 per pack of 28, 8-week duration (n=1).
#Glecaprevir/pibrentasvir, 100/40mg at £12,993.66 per pack of 84, 8-week duration (n=9); Sofosbuvir/velpatasvir, 400/100mg at £12,993.33 per pack of 28 tablets, 8-week duration (n=1).
Excludes treatment costs for one individual whose medication costs were not incurred by the health service.

††Glecaprevir/pibrentasvir, 100/40mg at £12,993.66 per pack of 84, 8-week duration (n=16).
Note: costs for testing are inclusive of staff time.
Abbreviations: RNA, ribonucleic acid; SVR, sustained virologic response.

In the qualitative analysis, six (75%) of eight invited staff involved in delivery of the prison HCV pathway participated in five semi-structured interviews (two group, three individual), with representation from service leadership, laboratory, and nursing staff. The largest proportion of facilitators were within the *characteristics of individuals* CFIR domain, and barriers in the *inner setting* domain (Table 4).

Table 4: Proportion of implementation determinants in each CFIR domain.

Determinants	**CFIR domain**				
	Intervention characteristics	Outer setting	Inner setting	Characteristics of individuals	Process
Facilitators – n (%)	6 (20.7)	5 (17.2)	6 (20.7)	8 (27.6)	4 (13.8)
Barriers – n (%)	5 (12.2)	2 (4.9)	13 (31.7)	9 (21.9)	12 (29.3)

Abbreviations: CFIR, Consolidated Framework for Implementation Research.
Notes: Percentages are proportions of all barriers/facilitators across CFIR domains.

In total, 41 barriers and 29 facilitators were identified (Table 5). To briefly summarise some key determinants, the analysis highlighted concerns around the manual result notification process, which utilised an amended micro-biology sample processing form to notify PoC results to central laboratory staff, for example:

> *If that bit of paper goes missing, the result's missing […] there's potential for, like, transcription errors […] there is a temptation as well, if you're really busy, to put them on the backburner and leave them.*
>
> – Biomedical scientist

On the device itself, interpreting viral load quantification output on the GeneXpert raised issues, as it was difficult to understand:

> *I checked it yesterday, to go and just to see, it was like, '7.52e05'.*
>
> *That doesn't mean anything to anybody...*
>
> *The lab phoned for me […] they couldn't understand the result, they didn't know what it was […] it came up '7.52e', and they were querying that.*
>
> – Nurse

Also, there were perceived challenges around co-operative teamworking between NHS and prison staff in engaging prison residents in implementing HCV testing, including the PoC testing approach:

> *There's a lot of 'refusals' […] we've never been able to work out what that refusal is caused by […] they've now got to fill in a form to say why they refused, and they're not getting done.*
>
> – Nurse

Manual handling of assays and related consumables, particularly with respect to infection control, was a source of anxiety:

> *It's messy, with the fingerprick and things, it's messy […] from an infection control sense it's a lot messier.*
>
> *We don't want to damage that fin [on the assay]. I'm paranoid about that, I really am.*
>
> – Nurse

Over and above these barriers, there were concerns around integrating the GeneXpert into usual workflow, task prioritisation, and staff turnover (see Table 5). On the other hand, the analysis uncovered multiple perceived facilitators of implementation, for example, the rapidity of results:

> *I was able to go and give them their results before I went home, so it's great!*
>
> – Nurse
>
> *You've got the difference between getting a result you can act upon, rather than having to wait a week. So, that's a major advantage.*
>
> – Leadership

Additionally, the increased flexibility in clinic times made possible by the option of PoC testing was viewed favourably:

> *That's a good point […] because the bloods go away [are sent to the laboratory] at half past 12. So, PCR really needs to be done in the morning.*
>
> *It wouldn't have to get sent off…*
>
> *It takes away all the barriers doesn't it*
>
> *…you can extend that clinic then. Into the afternoon because you've not got that cut-off at half past 12.*

– Nurse

Perceived patient preferences, i.e. preferring capillary/fingerstick sampling to conventional phlebotomy, were seen as a facilitator to implementation, as nurses could engage individuals who were otherwise disinterested:

> *I've got one guy waiting for this machine because he refuses point-blank to get, get needles in him.*
>
> – Nurse

In addition to these key facilitators, supportive colleagues, the wider evidence base for PoC testing, and the mobility of the device were viewed as positively influential on implementing the GeneXpert in the prison.

Table 5: List of all determinants to implementation of the Cepheid GeneXpert in HMP Perth identified in semi-structured staff interviews(n=70).

Domain	Barriers (n=41)
Inner setting	Leadership staff felt individual custody trumped healthcare in the prison, hindering improvements to care.
	Laboratory staff did not prioritise uploading GeneXpert results as they did not perform the test.
	Laboratory staff did not prioritise reporting GeneXpert results because it was a pilot project.
	Leadership staff felt that, as the nurses were not present for the majority of admissions, in-reach was limited.
	Leadership staff felt a lack of freedom to operate in the prison hindered the design of the pathway.
	Clinical staff felt the lack of physical space and clinic rooms adversely affected how and when the GeneXpert could be used.
	Clinical staff were limited to using the GeneXpert and obtaining samples for testing in specific locations in the prison.
	Clinical staff found it difficult to transit individuals from residential areas of the prison the health centre due to the need for intermediary 'runners'.
	Clinical staff felt pressured by SPS staff ('runners') to finish clinic appointments quickly.
	Clinical staff found it difficult to implement healthcare initiatives as it was perceived as secondary to the regimental running of the prison/security.
	Clinical staff found it difficult to engage colleagues outside their direct team in HCV testing due to perceived lack of integrated care.
	The GeneXpert was seen as difficult to implement in the long-term due to high staff turnover in the prison.
	Laboratory staff found it difficult to log results in a timely manner due to staff turnover and training issues.

Outer setting	Laboratory staff felt uncertainty around whether reporting tasks could be delegated to administrative staff due to professional regulations. Laboratory staff found it difficult to manage the reporting workflow due to the pressures of the Covid-19 pandemic.
Characteristics of Individuals	Leadership staff felt a lack of awareness of HCV among people in prison and prison staff hindered improvements to prison care. Laboratory staff did not see administration of GeneXpert results as part of their job/in line with their skillset. Laboratory staff felt uncertain about the value of their role in the reporting process. Clinical staff felt cynical about whether SPS staff 'runners' actually approached individuals to inform them their attendance at the health centre was required. Clinical staff indicated a preference to obtain a venous sample to fingerprick sample due to their self-perceived proficiency at obtaining venous bloods. Clinical staff viewed fingerprick sampling method as slower than obtaining venous samples. Clinical staff often wanted to know antibody status of an individual, meaning at times they may not have prioritised PCR testing with GeneXpert. Clinical staff felt obtaining fingerpick samples using the minivette introduced infection control concerns. Laboratory staff felt unsure about the value of their role in the result reporting process.
Intervention characteristics	Leadership staff felt the need to return to device to check result after one hour made it difficult to plan work for a clinic when they had competing priorities for their time. Performing a GeneXpert test was perceived as more work than obtaining conventional samples and sending them for lab analysis, by leadership staff. Transporting GeneXpert test assays in the prison caused anxiety for clinical staff due to the sensitivity of the rear fin on the cartridge. Clinical staff felt the dexterity required to correctly insert the sample into the cartridge caused errors in results. Laboratory and clinical staff found it challenging to interpret the viral load quantification output (scientific notation) from the device.
Process	Laboratory staff felt the lack of an IT link raised concerns about accurate result reporting. Laboratory staff found it difficult to plan/implement an SOP for reporting results, as they were unsure what to expect in terms of volume of tests. Clinical staff had difficulty conceptualising how the device would be used due to a lack of a plan on who to target for testing and how to do so. Clinical staff found it difficult to plan a 'one-day' test/treat pathway due to safety concerns with the frontline medication used. Clinical staff found it difficult to transit individuals to the prison health centre due to the provision of OAT at concurrent time to BBV clinics. The GeneXpert process was viewed as time-consuming and difficult to implement systematically due to unpredictable nurse workload.

	Laboratory staff did not prioritise uploading test results to electronic systems because they did not perform the test themselves. The paper reporting process was felt to introduce potential for result reporting/transcription errors. Laboratory staff found it difficult to adapt to the paper/manual reporting workflow as it was unfamiliar to them. Laboratory staff felt there was poor communication between themselves and clinical staff implementing the testing. Clinical staff found it difficult to verify patients' CHI numbers as they are not routinely used in the prison system. Clinical staff were anxious about the paper reporting process because it placed a high degree of responsibility on them not to make reporting errors.
	Facilitators (n=29)
Inner setting	Laboratory staff were open to challenge on results incorrectly uploaded due to their perceived professional responsibility to ensure accuracy. Clinical staff found it easier to plan engagement with testing by co-designing awareness materials with people in prison. Clinical staff found it easier to implement the GeneXpert pathway because of previous testing undertaken in the prison for diabetes by another team. Clinical staff found it easier to navigate the prison environment for testing after being 'key trained'. The prison BBV nursing team's openness to change and credibility with prison staff was perceived as helpful to implementation, by leadership staff. Clinical staff found it easier to engage patients due to the ethos of their team which values individual relationships.
Outer setting	The local HCV elimination strategy was seen as facilitative of improving care by leadership staff. MCN infrastructure and inter-organisational working was seen as facilitative of improving prison BBV care by leadership staff. GeneXpert was viewed as preferable for sampling in patients with difficult venous access by clinical staff. Some people in prison indicated a preference to clinical staff to be tested using the GeneXpert due to the non-invasive sampling. Clinical staff found it easier to implement the GeneXpert pathway as the virology team were perceived as supportive.
Characteristics of Individuals	Laboratory staff felt prior experience with reference result reporting and prior PoC pilots for flu were helpful in implementing the result reporting workflow for the GeneXpert. Laboratory staff appreciated the unique testing challenges in the prison environment. Laboratory staff perceived GeneXpert testing in the prison as innovative. Wider knowledge of GeneXpert testing in other UK cities among laboratory staff and individual advocacy among those staff facilitated the decision to support the project. Clinical staff trusted the results from the GeneXpert due to an awareness other teams were using them.

	Clinical staff perceived the GeneXpert as making their job easier. New staff in the prison health centre were perceived as being open to change by existing clinical staff. Clinical staff perceived the GeneXpert as enabling quicker transition from diagnosis to treatment.
Intervention characteristics	Leadership staff felt the strong existing evidence base on the clinical effectiveness of the GeneXpert and benefits of HCV treatment for PWID facilitated implementation. Laboratory staff found it easier to integrate the GeneXpert as there were no financial implications to do so. Clinical staff found it easier plan their use of the GeneXpert as it was mobile (on trolley). Clinical staff could plan afternoon clinics/more flexible clinic times as the GeneXpert made the 12.30 bloods cut-off inapplicable for PCRs. Leadership staff felt that GeneXpert delivered quick, actionable, results and was easy to use. GeneXpert was perceived as preferable to conventional testing due to the speed of the results by leadership staff.
Process	Laboratory staff felt existing lab systems could be easily amended to integrate the GeneXpert test platform. Clinical staff found it easier to engage people in prison into testing by building rapport with and disseminating HCV information via 'pass men'. Laboratory staff felt integrating the GeneXpert process as a whole was minimally disruptive to their usual work. Laboratory staff felt it was an easier process compared to conventional testing as they did not have to process the samples themselves.

Abbreviations: HMP, Her Majesty's Prison Service; HCV, hepatitis c virus infection; IT, information technology; SOP, standard operating procedure; OAT, opioid agonist therapy; BBV, blood-borne virus; SPS, Scottish Prison Service; CHI, community health index; MCN, managed care network; PoC, point-of-care; UK, United Kingdom; PWID, people who inject drugs; PCR, polymerase chain reaction.

Discussion

Interventions to enhance transition to HCV treatment are required for critical populations, including incarcerated people, if WHO 2030 elimination goals are to be realised.[28,29] This single-site evaluation has demonstrated that it is clinically beneficial to implement on-site nurse-led PoC RNA testing for HCV in a maximum-security Scottish prison. One-hundred and sixty-seven PoC tests were administered and, among individuals who tested HCV positive, those who received one had increased likelihood of initiating treatment sooner than those tested conventionally. This effect was observed in both the main models and simplified supplementary models, though the magnitude of the effect is likely most realistic in model one reported here (19 vs 33 days; *a*HR 1.91 [1.03–3.55]), which compared PoC testing to

conventional service delivery unincumbered by the effects of COVID-19. However, the proportion of error/invalid tests in our pilot was higher than observed in other real-world settings. For example, an Australian study implemented PoC RNA testing in needle and syringe provision (NSP) sites, where testing was undertaken by non-healthcare staff.[30] In this study, 1.4% (2/140) of all PoC RNA tests were invalid. Another study implemented the same intervention across harm reduction centres in Georgia.[31] The error rate was slightly higher in this study at 3.6% (22/619) – and most were related to operator error, similar to our findings – but still much lower than the rate in our evaluation. The number of failed tests did attenuate over time (Figure S2), which suggests an association with operator proficiency (i.e. a learning curve).

As noted in the qualitative results, staff turnover was an issue in this pilot, which is common in prison health services.[32] This may have impacted upon Xpert® error rates. The laboratory services also experienced high staff turnover and difficulties managing the reporting workflow due to Covid-19 (Table 5). This somewhat explains the proportion of result reporting inaccuracies which occurred, particularly the spike in June 2020 (Figure S3) and the following months as services remobilised following the initial covid outbreak. Ensuring prompt and adequate training for new staff will be critical to reducing the likelihood of errors going forward.

The cost analysis suggested that employing this PoC RNA an approach may not be cost favourable. Price differences appeared to be impacted by: a) the significant difference in linkage-to-treatment for the GeneXpert group relative to the conventional group in the pilot phase, which incurred higher treatment costs; b) the proportion of RNA tests in the pilot phase which were Xpert® rather than conventional, meaning higher overall testing costs, despite the lower cost-per-test at the individual level; and c) LTFU among those who started treatment, which was proportionally higher in the GeneXpert group (5/16; 38%), relative to those conventionally tested in pre-pilot (7/33; 21%) and pilot (0/11; 0%) phases. Improved linkage-to-treatment is important to consider when choosing whether to implement such

interventions because, with the high efficacy of DAA treatment, LTFU individuals are likely to have achieved SVR.[12] The costs of a relatively less efficient pathway may be higher with respect to enduring HCV transmission and its attendant consequences. In the hypothesised scenario of maximum discounting of DAAs, and cure attainment among those LTFU, the GeneXpert group costs became favourable relative to the pre-pilot phase. For others considering a similar approach, consideration might be given to this, as well as the identified implementation determinants.

Bringing quickly actionable HCV testing closer to incarcerated people has been increasingly advocated in recent years.[33–35] The primary results reported here align with recent similar research. A study undertaken in HMP Wormwood Scrubs, England, reduced time from screening to treatment from three months, for those tested by DBS, to one week, by implementing PoC RNA testing and augmenting it with a streamlined care pathway.[36] However, processing of GeneXpert samples was not undertaken on site. Similarly, an Australian study reported high test uptake and shortened transition to treatment among a cohort screened upon reception using a one-stop approach including PoC RNA testing with additional fast-track components. Initial results indicated those tested by PoC had shorter time from testing to treatment (6 v 90 days; $p<0.001$) as well as high treatment uptake, similar to our findings.[37] Although views of imprisoned people on the acceptability of PoC testing did not form part of the work undertaken here, other studies have examined this. A qualitative sub-study on the Australian project showed the PoC intervention was highly acceptable to participants.[38] Other work found testing in this manner highly acceptable, with most preferring it to venepuncture.[39] Further, a Canadian study found PoC fingerprick HCV testing was highly preferred to conventional venepuncture for those with challenging venous access, which we also observed in the qualitative analysis.[40]

Currently we know what works well for HCV diagnosis and treatment on a technical level.[41] Therefore, we have reported multiple determinants of implementation with the intention of informing projects undertaken elsewhere (Table 5). Overall, the results implied an underlying

tension between individual knowledge, self-efficacy, and organisational culture, with leadership, readiness to implement, and prioritisation of work. In the *inner setting*, most barriers were associated with the constrained nature in which clinical staff could operate within the prison; the relative priority of healthcare in the prison environment; staff turnover and training issues; and the relative priority of the pilot to laboratory staff. Most facilitators were in the *characteristics of individuals* domain. They predominantly spanned existing knowledge of the GeneXpert platform; prior experience with PoC testing for other clinical indications; a perception of the GeneXpert as innovative and easing workloads; and a perceived openness to change among nursing staff. In *intervention characteristics*, staff felt the need to return to the device after 60 minutes to conclude the process was inconvenient relative to conventional methods. Further, the sensitivity of the assays to external forces; the way the device reports viral load quantification; and obtaining fingerprick samples were all observed as challenges.

Conversely, the evidence around the GeneXpert; the mobility of the device; its impact on clinic planning; and the rapidity of test results were all positive influences. In the *process* domain, the result reporting procedure, although effective, was less attractive than an automated electronic system. Of the PoC tests with some level of inaccurate information on electronic health records (Table S6, Figure S3), most, if not all, could have been avoided with an automated electronic result reporting system. Other programs integrating PoC RNA testing into routine BBV care should give serious consideration to developing such a link. Finally, in the *outer setting*, professional regulations made it difficult to delegate certain tasks to alternative staff members, and impacts related to COVID-19 made the reporting workflow challenging to manage within the laboratory. Overall, in the wider regional context, the HCV elimination strategy in Tayside, along with the organisational structures which govern it, were seen as facilitative. We hope that by reporting the determinants of implementation against a recognised transferrable framework, we can increase their relevance across divergent settings and contribute to program design elsewhere.

This evaluation has multiple limitations. We did not seek the views of patients on the acceptability of PoC RNA testing, due to the nature of the work which was focused primarily on implementation from a health systems perspective and inherently limited in scope. Beyond this, the qualitative analysis used convenience sampling, which is non-random and prone to motivation bias and limited generalisability.[42] Determinants reported here may thus not be representative of other jurisdictions that have run similar projects, and future comparative studies would be valuable to determine this when the literature base is more robust. Additionally, in the qualitative work, diverging interview methods were used (focus group and one-to-one), with attendant strengths and weaknesses. The focus group approach, for example, could have led to hesitance in expressing views in the presence of staff of differing seniority, minimal expression of deviating opinions, limited discussion due to confidentiality or disclosure issues, or bias from moderator intervention.[43,44] Conversely, individual interviews may have generated interviewee self-consciousness; lacked the spontaneity of group discussion; and struggled to describe the commonness of issues raised.[45] These biases and issues will inherently have affected the quality of data. All interviews may have been biased by interviewee familiarity with the interviewer/facilitator, and the interviewer's existing knowledge of the intervention. Further, the sample who participated in qualitative interviews was limited – almost all relevant staff (nurses, biomedical staff, service leadership, commissioning staff) participated – but may raise concerns regarding 'saturation'. With respect to this, given the specialised knowledge of participants; their relevance to the pathway; the use of an established theoretical framework; and a pre-specified analysis strategy, the concept of 'information power' is relevant.[46] This suggests the more information a sample holds, relevant to the evaluation, and where scrutiny is informed by a theoretical framework, the fewer participants are required to 'saturate' the analysis. In taking an approach conceptually aligned with this view, we hoped to ameliorate some of the challenges associated with the qualitative strand of the evaluation. Other limitations include the impact of COVID-19 on laboratory testing turnaround times during the pilot, which may have disadvantaged the conventional group in the survival

analysis, and the rudimentary approach to the cost analysis, which only included direct costs. Finally, the survival data frame was right censored for some cases, meaning their exact survival time was uncertain.

Conclusions

The results suggest that integrating the Cepheid GeneXpert platform into routine nurse-led HCV care in a maximum-security prison health centre improves linkage to treatment in the Scottish context. Our data augments the available literature with respect to the benefits of this approach on linkage to care, but reports gains which are more modest, possibly driven by the absence of additional care pathway changes reported by others. Multiple determinants to implementation were highlighted, which may inform similar pilots in other prisons. The new platform was less favourable in cost terms than conventional testing; however, this was affected by several factors (linkage to treatment, LTFU), and in realistic hypothesised scenarios multiple favourable cost outcomes were observed. Consequent of this pilot, we are now undertaking further research informed by this work with this testing platform in local NSP sites, and a comparable analysis is planned.

Appendices

Author contributions

CJB, SKI, and JFD conceptualised the evaluation. CJB curated data; selected the methodologies employed; undertook qualitative and quantitative analyses; visualised data; and wrote the original draft. SKI and JFD provided supervision. AM undertook qualitative data analysis. All authors contributed to revisions and approved the final version of the manuscript. CJB had full access to the data and takes responsibility for the integrity of the data and the accuracy of analysis.

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Competing interests

CJB, AM, and SKI, have no disclosures. JFD reports grants and personal fees from AbbVie; grants and personal fees from Gilead; and grants and personal fees from MSD, outside the submitted work.

Patient and public involvement

Patients and members of the public were not involved in the design or conduct of this work.

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Data availability statement

Quantitative data underpinning this study were obtained from routinely updated NHS health records in line with approval granted by the NHS Caldicott Guardian. The individuals to whom the data pertains did not explicitly consent to its use for research purposes. Therefore,

it is not possible for the authors to share this data. However, interested parties can make specific requests to NHS Tayside Information Governance by email on: informationgovernance.tayside@nhs.scot. Consideration will be given to sharing qualitative data upon receipt of a methodologically sound proposal and will be subject to the agreement of interview participants.

Ethics Approval

As this was a retrospective service evaluation – such evaluations may include access to patient data, as well as provision of questionnaires and interviews without NHS ethical review (as such work is not classed as 'research' by the NHS Research Ethics Service) – NHS ethical review was not required.[47] Instead, Caldicott Guardian approval was obtained for data access (IGTCAL7004). This process reviews internal NHS evaluations, ensuring the protection and appropriate use of patient data. The evaluation was also registered with the NHS Tayside clinical governance group for prison healthcare (ref: 27/19).

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Figure legends

Figure 1: Summary of observation dates and study activities.

Note: Conventional testing was by whole blood sent to a laboratory for analysis and dried blood spot methods.

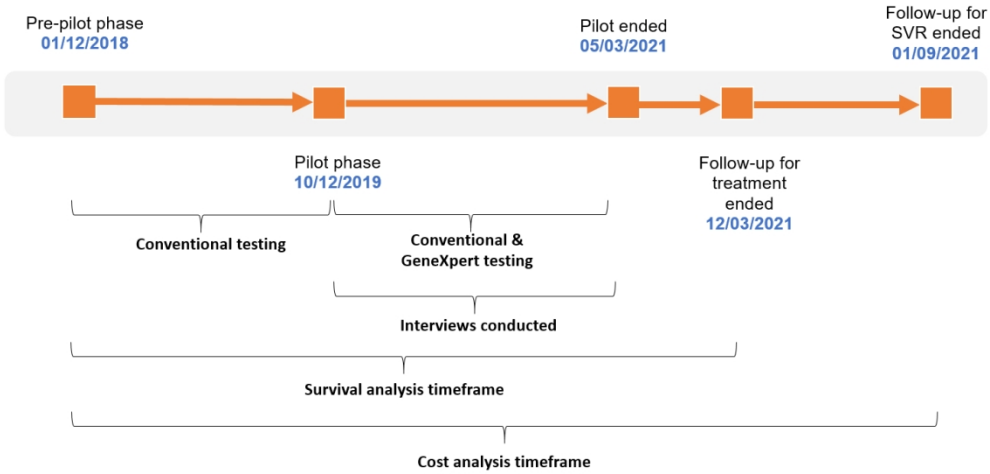
Figure 2: Target cohort profile with related clinical outcomes and censoring.

*Cases received treatment but excluded from cost and time-to-treatment analyses, as their testing data was unavailable or unverifiable.

†All censored in survival analysis at relevant decease, liberation, transfer, or follow-up censor dates.

Notes: Group 1 are those tested conventionally from 2018-19 (reference period); group 2 are those conventionally tested during the pilot phase (2019-21); group 3 are those tested with the GeneXpert during the pilot phase (2019-21).

Abbreviations: RNA, ribonucleic acid; RNA+, ribonucleic acid positive (actively infected); PoC, point of care; SVR, sustained virologic response; LTFU; lost to follow up.



Summary of observation dates and study activities.

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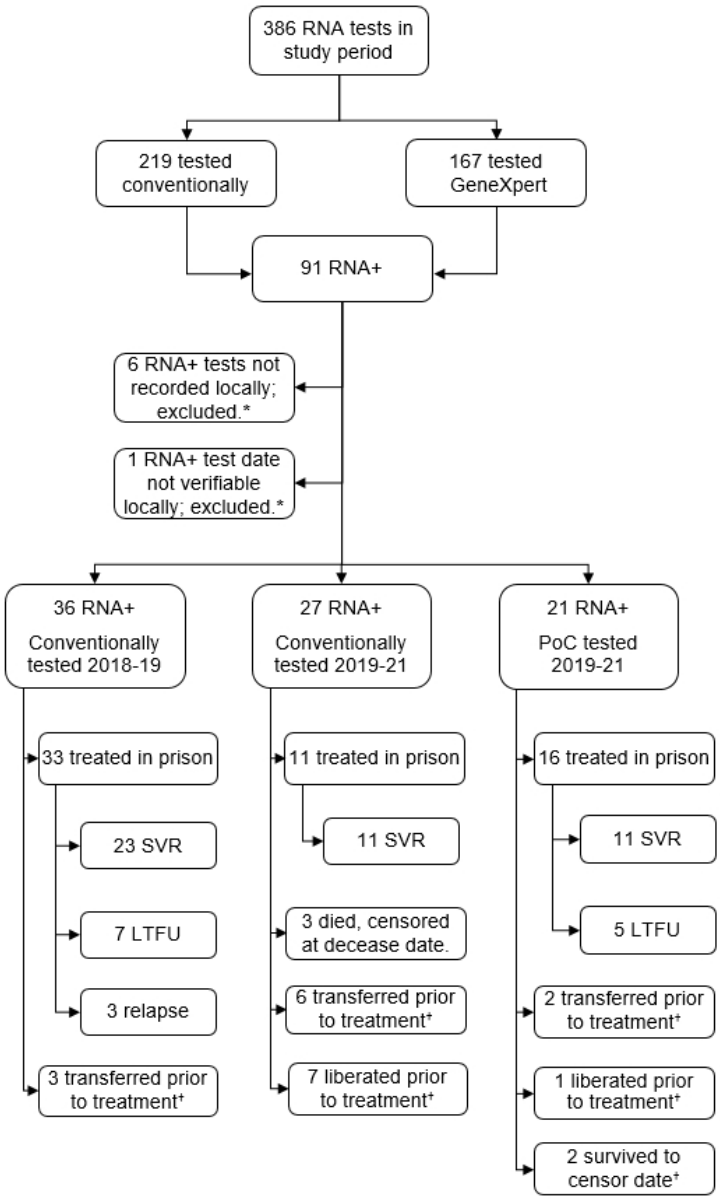

Target cohort profile with related clinical outcomes and censoring.

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Appendix S1

A mixed-methods evaluation of point-of-care hepatitis c virus RNA testing in a Scottish Prison.

Christopher J Byrne[1,2] Amy Malaguti[3,4] Sarah K Inglis[2] John F Dillon[1,5]

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Table S1: Proportional hazards models stratified by test type (n=84).

	Variable	n (%)	HR (95%CI)	*p*
Model 1	Conventionally tested (ref)	63 (75.0)	…	
	GeneXpert tested	21 (25.0)	2.52 (1.40–4.52)	.002
	Variable	**n (%)**	***a*HR (95%CI)**	***p***
Model 2	Conventionally tested (ref)	63 (75.0)	…	
	GeneXpert tested	21 (25.0)	3.54 (1.41–4.59)	.002
	Age at test	…	1.03 (0.99–1.07)	.103

Abbreviations: PH, Proportional hazards; aHR, adjusted hazard ratio; CI, confidence interval.
Model 1 fit: X^2=8.23, p=0.004. Harrell's C: 0.63 (95% CI 0.56-0.70), p = <.0001.
Model 2 fit: X^2=10.86, p=0.004. Harrell's C: 0.63 (95% CI 0.55-0.72), p = <.0001.
Survival information both models: failures = 60; time at risk = 4,719 days.
Note: Unadjusted (model 1) and age-adjusted (model 2) proportional hazards models with cases grouped depending on which HCV test they received during the pilot (conventional phlebotomy/dried blood spot or point-of-care using the Xpert fingerstick assay).

Table S2: Focus group prompt questions.

Pre-implementation FG	Post implementation FG
What is the current pathway from the patient's perspective for getting a hepatitis c test in the prison?	So far, do you think the GeneXpert is 'working' in the prison?
Why, in your view, is the GeneXpert being brought into the prison?	What barriers/facilitators have you encountered using it?
How do you think using the GeneXpert will compare with current HCV testing methods?	Have any disadvantages to using the GeneXpert arisen since you started using it?
What do you think will be the advantages and disadvantages of the GeneXpert in the prison environment?	How have your patients responded to the offer of a test with the GeneXpert?
How do you expect the prison environment to affect the way you use the GeneXpert?	Has the pharmacy got a stock of HCV medication? This was perceived as a barrier to reducing waiting times when we last met.
Is there anything you like to use the device for, but expect you can or cannot do?	Have you had any issues with NHS virology since you started reporting results from the GeneXpert?
How do you feel about introducing the GeneXpert to the prison? [*prompt: autonomy; trust]*	Do you feel like you've had enough support and resources in implementing the new pathway?
How confident do you feel using it?	You mentioned you would like to take samples for GeneXpert tests in the halls when we last met, is this something that has been possible? [*why?*]
How will you decide to use the GeneXpert instead of another test, like a dried blood spot or oral swab? [*prompt: clinical history; patient preference*]	Last time you mentioned transferring patients to the health centre as a barrier to testing, is this still the case? Has the GeneXpert addressed that in any way?
Thinking of prisoners in HMP Perth: how do you think getting a hepatitis c test makes them feel using current methods?	You all felt confident using the device last time we spoke, is this still the case?
What do you think is their [prisoners'] preferred method of getting a test?	Has the GeneXpert changed your job for better or worse?

Do you think offering a test using the GeneXpert will make them react differently? What barriers do prisoners face in receiving a hepatitis c test in the prison? Will the GeneXpert help to get around any of those? How will you encourage more prisoners to take a test, will the GeneXpert play a role? Do you think the current system will be improved with the GeneXpert, or will it raise more problems than it solves? Have you seen or heard of any other places using the GeneXpert for hepatitis c testing? Do you think the prison health centre is open to changing processes? What strategies have you designed for implementing the GeneXpert? Have you needed to work with people outside your usual team? [*prompt: SPS staff*] What will be your measure of success or failure of the GeneXpert in the prison? Do you plan to change any other aspects of prisoner HCV care at the same time as introducing the GeneXpert? [*prompt: medication; prescribing*] Is there anything we haven't discussed that you'd like to raise before we finish up?	You previously expected the GeneXpert to speed up your process for getting people onto treatment, has that been the case? Are you primarily using it as a diagnostic tool, or to monitor treatment response? [*why?*] Have you been starting people on treatment with just the result from the GeneXpert? Have you had any development in testing your OST population? Is there anything we haven't discussed that you'd like to raise before we finish up?

Abbreviations: FG, focus group; HCV, hepatitis c virus; HMP, His Majesty's Prison; SPS, Scottish Prison Service.
Note: Not all questions would have been asked, these were simply potential prompts to encourage reflection and thought, and facilitate discussion.

Table S3: Individual Interview prompt questions (leadership/clinical staff).
What are your thoughts about why the GeneXpert is being implemented by the blood-borne virus service in HMP Perth?
How effective do you think the GeneXpert can be in HMP Perth? [*follow: why?*]
What (dis)advantages do you think the GeneXpert has compared to existing hepatis c testing in HMP Perth? [*follow: What are the relative (dis)advantages?]*
What issues do you think prisoners face to participating in hepatitis c testing with the GeneXpert?
What issues do you think staff face to delivering hepatitis c testing with the GeneXpert?
To what extent does implementing the GeneXpert fit with the wider goals of the blood-borne virus service? [*follow: How do these goals affect implementation?*]
To what extent were the needs and preferences of prisoners considered when deciding to implement the GeneXpert?
How do you think the prison infrastructure affects use of the GeneXpert? [*prompt: Physical layout, size, staff, or prison capacity.*]
What kind of policies or guidelines influenced the decision to use the GeneXpert in HMP Perth? [*follow: How did they influence the decision?*]
How do you think the culture of the blood-borne virus service/team influences implementation of the GeneXpert?
Who were the key influential individuals to get on board to implement this new device? [*follow: Was their involvement helpful, or a hindrance?*]
Is there anything you would like to discuss that we have not already covered?
Abbreviations: HMP, His Majesty's Prison

Table S4: Individual Interview prompt questions (laboratory staff).

How does supporting the GeneXpert compare to existing hepatitis c testing supported by virology? [*follow: Advantages disadvantages?*]
Can you describe any workflow changes made to support GeneXpert testing? [*follow: What were they? Were these easy to do?*]
Can you describe any infrastructure changes that had to be made in virology to support the GeneXpert platform? [*follow: Costly? Challenges?*]
How well do you think the GeneXpert testing method integrates with the wider Virology services? [*follow: Why?*]
How well do you think Virology's support of the GeneXpert meet the needs of the clinical teams using it? [*follow: Why?*]
What is the general feeling in Virology towards supporting this new testing method? [*follow: How did this influence support for GeneXpert testing?*]
How does HCV GeneXpert testing fit with existing processes in Virology?
How confident do you feel personally in your ability to support testing for HCV using the GeneXpert?
What do you think about the test result notification process for the GeneXpert?
Did Virology produce any SOPs or guidance to support GeneXpert testing? [*follow: If yes, describe. Easy to understand/adhere to?*]
How do you and your colleagues communicate with the clinical staff doing the testing with the GeneXpert? [*follow: Pros/Cons?*]
Is there anything you would like to discuss that we have not already covered?

Abbreviations: HCV, hepatitis c virus.

Table S5: Individual Interview prompt questions (leadership/commissioning staff).
What are your thoughts about the GeneXpert and its implementation in HMP Perth?
Theoretically, what (dis)advantages do you think the GeneXpert offers compared to standard testing in the prison?
How does implementing the GeneXpert in the prison fit with wider MCN policy and goals?
What barriers do you think prisoners face in getting tested with the GeneXpert in HMP Perth?
What facilitators do you think the prison creates in testing prisoners with the GeneXpert?
What are some of the administrative, logistical, or policy barriers and facilitators to implementing the GeneXpert in Tayside BBV network?
Theoretically, how do you think the infrastructure of the prison (layout etc.) could affect implementation of the GeneXpert?
To what extent would you say new projects/devices like this are embraced within the Tayside Managed Care Network?
Is there anything you would like to discuss that we have not already covered?
Abbreviations: HMP, His Majesty's Prison; MCN, managed care network; HCV, hepatitis c virus; BBV, blood-borne virus.

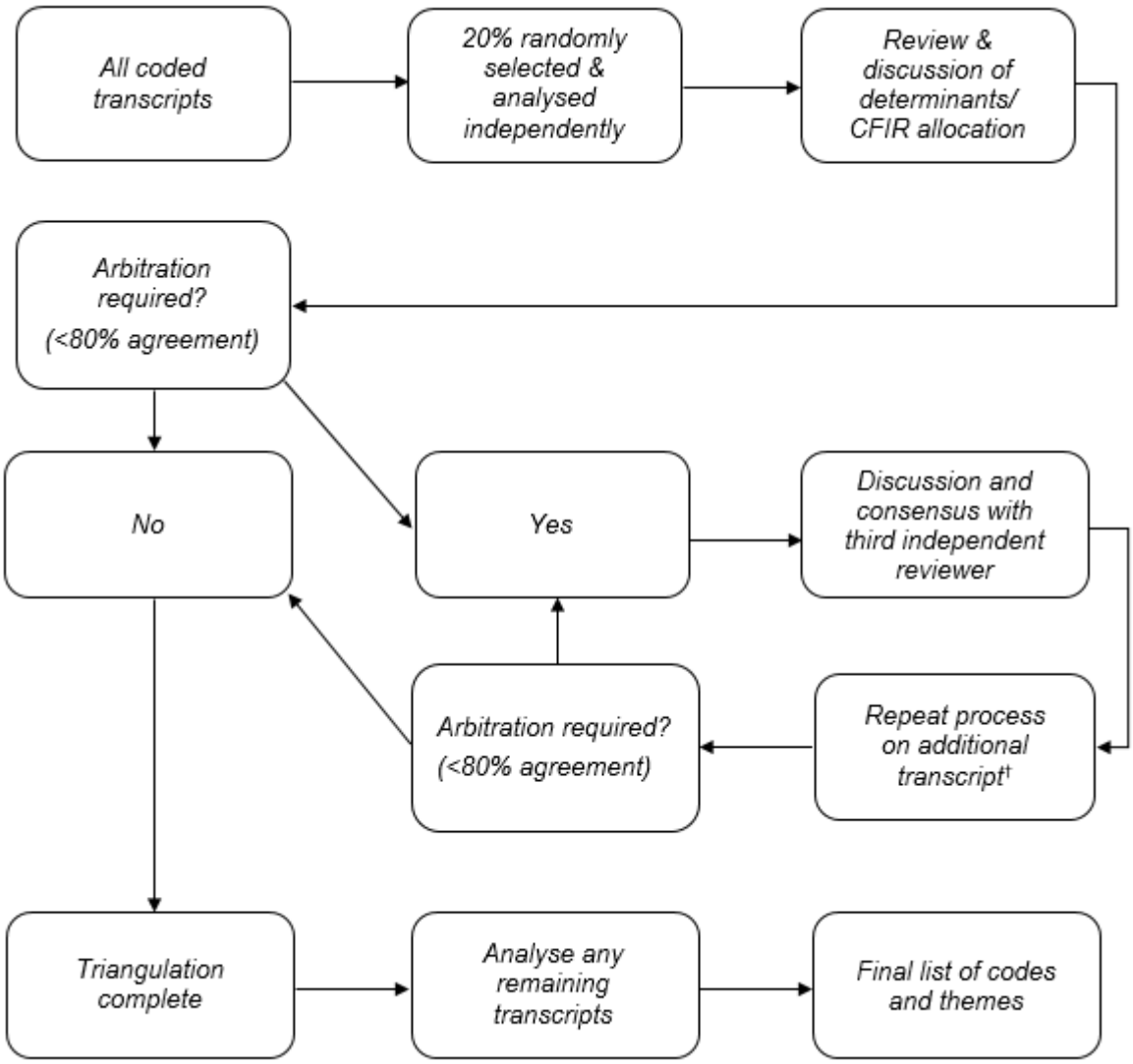

Figure S1: Pre-specified qualitative triangulation algorithm.
†If no transcripts remaining, triangulation is complete.

Table S6: Point-of-care test result reporting errors.

Issue encountered	n
Test not reported on ICE	16
ICE report states sample type oral fluid	7
Test reported on ICE, result not specified	2
ICE report specifies inaccurate result	1
ICE report specifies inaccurate test date	2
Total	28

Abbreviations: HMP, His Majesty's Prison service; ICE, integrated clinical environment.
Note: ICE is the local electronic health record system for recording clinical tests administered to patients.

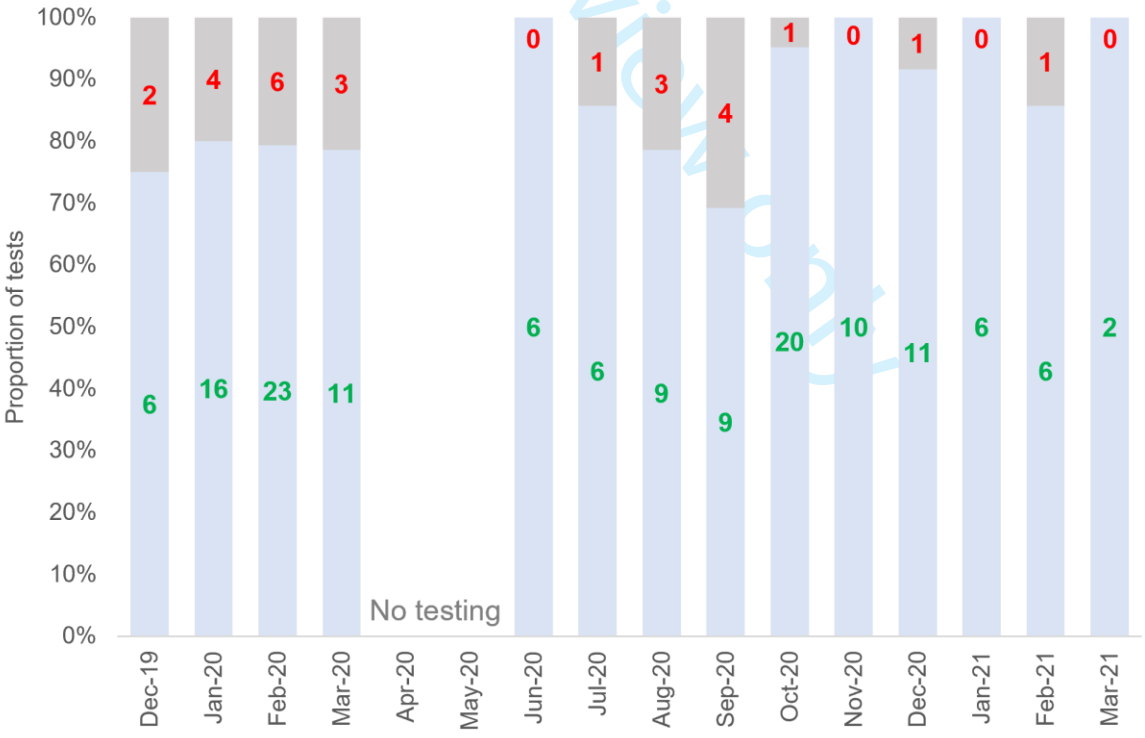

Figure S2: Number of completed (in green) and failed (in red) Xpert® Fingerstick RNA tests per month demonstrating a proportionate decrease over time.
Note: Failed tests include both ERROR (n=23), which were operator related, and INVALID (n=3), which were not operator related, results.

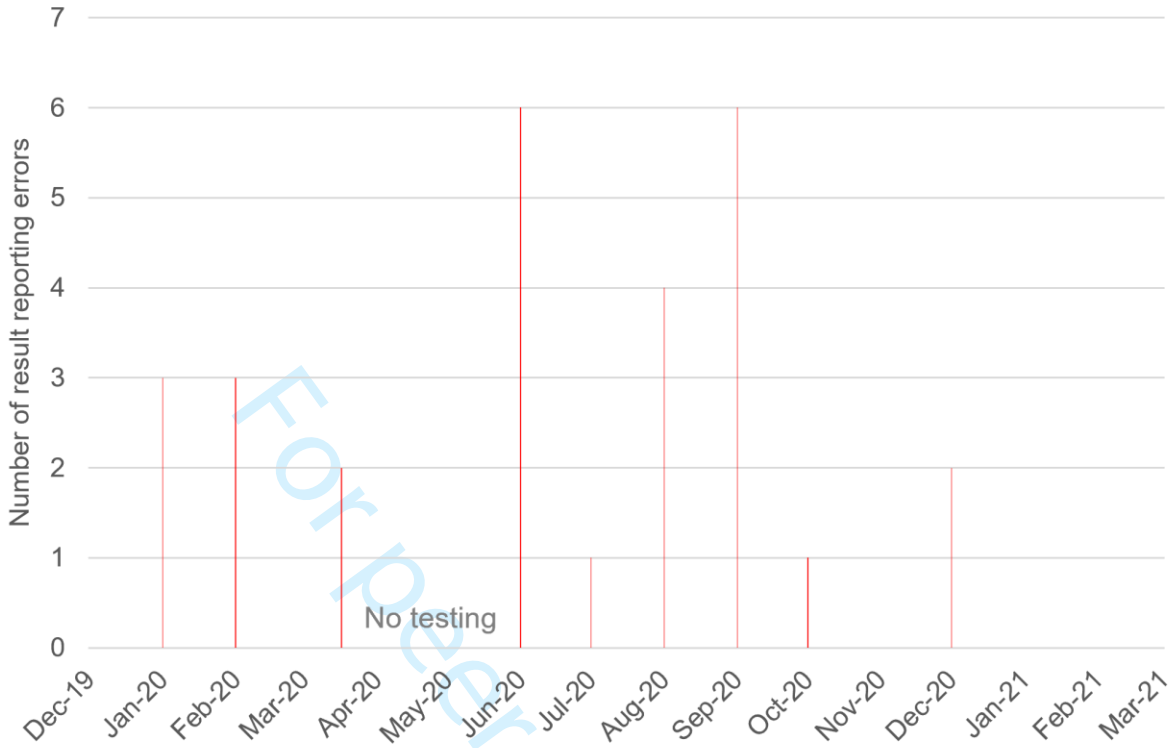

Figure S3: Number of Xpert® Fingerstick RNA test result reporting errors over time.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	PAGE
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5-6
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6-9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-9
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	7-8
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-10
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	7-8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8-9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9
		(*b*) Describe any methods used to examine subgroups and interactions	8-9
		(*c*) Explain how missing data were addressed	8-9
		(*d*) If applicable, explain how loss to follow-up was addressed	8-9
		(*e*) Describe any sensitivity analyses	…
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	10
		(c) Consider use of a flow diagram	Fig 2
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10; table 1
		(b) Indicate number of participants with missing data for each variable of interest	10-11; Fig 2
		(c) Summarise follow-up time (eg, average and total amount)	10; 12; table 2
Outcome data	15*	Report numbers of outcome events or summary measures over time	10-12
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted	10-12;

		estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	table 2
		(*b*) Report category boundaries when continuous variables were categorized	…
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	…
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	13-19
Discussion			
Key results	18	Summarise key results with reference to study objectives	19-20
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	23-24
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	24
Generalisability	21	Discuss the generalisability (external validity) of the study results	4; 23
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	25

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.