NIHR | Innovation Observatory

Newcastle University

Horizon Scanning Final Report: Identification of Respiratory Tract Infection Technologies

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Introduction

The NIHR Innovation Observatory's Medical Devices (MDx) team has completed the horizon scanning of the second of four clinical pathways, for the identification of technological innovations (e.g. products/interventions) that have the potential to reduce demand for antimicrobials through infection prevention, detection and or management intervention.

The innovation landscape presented for Respiratory Tract Infections (RTIs) aims to inform decisions by NHSE & I's AMR Programme Board, and accelerate adoption of proven innovations that will enhance appropriate antimicrobial prescribing and improve patient outcomes. This report (accompanied with the complete Excel RTI and COVID-19 datasets) provides important, immediately relevant data on key areas of development, to allow readers to evaluate the potential impact of these innovations and identify promising technologies for use in the NHS (or wider). To help with clarity and comprehensibility, the report has been organised and presented into three main sections:

1. Horizon scanning strategy – an overview of the search strategy devised to identify RTI detection technologies and related evidence

2. RTI detection technology landscape – the clinical trial, product pipeline and funding landscape result sections, each contain information (including visualised data) about the overarching global landscape of RTI technological innovations

3. Summary of key themes and emerging patterns, based on the results retrieved from the scan and market intelligence

It is hoped that the visualisations and accompanying narrative presented in this report (along with the complete Excel RTI and COVID-19 datasets), inform understanding and shape discussions on the availability of RTI innovative technologies developed for diagnostic purposes. The report also describes some of the key providers/developers in play for the international market and offers a snapshot of current products, including those with high innovation potential. Overall, our horizon scanning activities highlight that the evolution of RTI technology has the potential to offer significant opportunities in the NHS to deliver better outcomes.

Data Files:

All diagnostic innovations developed for non-severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) respiratory pathogens are compiled within the RTI dataset (NIHRIO RTI Pipeline Dataset). The diagnostic pipeline of SARS-CoV-2 tests in development or commercialised (including multiplex tests), are provided separately in the COVID-19 dataset (NIHRIO COVID-19 Pipeline Dataset). For ease, diagnostic tests within this dataset have been colour coded (by row), to indicate whether the test detect (based on information reported by developer/source):

a. Original SARS-CoV-2 strain only (no row colour i.e. no fill)
b. Original SARS-CoV-2 strain AND non-SARS-CoV-2 pathogen(s) (row colour blue)
c. Variant of SARS-CoV-2 OR multiple variants of SARS-CoV-2 (row colour orange)
d. Variant(s) of SARS-CoV-2 AND non-SARS-CoV-2 pathogen(s) (row colour grey)

Please note that all multiplex tests in the dataset (C-19 & RTI Multiplex tab) include 1) Original SARS-CoV-2 strain AND non-SARS-CoV-2 pathogen(s) (row colour blue) and 2) Variant(s) of SARS-CoV-2 AND non-SARS-CoV-2 pathogen(s) (row colour grey). These tests all detect SARS-CoV-2 (original strain/variant) and non-SARS-CoV-2 respiratory pathogen(s) such as Influenza A/B. Information pertaining to the non-SARS-CoV-2 pathogen(s) can be found in the Test column (H) and Turnaround Time/Other Info column (K). Details of the variant detected is captured in the Variant(s) Detected column (X). The COVID-19 dataset also includes information on whether the test is able to differentiate between pathogens on the test panel (column Y) in the C-19 & RTI Multiplex tab. Furthermore, performance data collated from Public Health England (PHE) and the Foundation for Innovative New Diagnostics (FIND) is presented for molecular and antigen tests (Performance MDx tab) and antibody tests (Performance IDx tab).

Methods

Horizon Scanning for RTI Diagnostic Technologies

The horizon scanning methodologies developed by the Innovation Observatory (IO) to identify the pipeline of RTI technologies, involved the identification of information sources that detected 'signals' for RTI detection technologies. The collection of primary and secondary sources identified, were systematically scanned using a combination of traditional scanning methods (manual), automated and novel AI/machine learning techniques.

Collation of Key Terms

Specific search strategies were formulated for the scans performed and combined MeSH/key terms identified with Boolean operators (where applicable). A comprehensive list of keywords and concepts was compiled by the IO's Information Specialist Team, based on the evidence reports provided by the AMR Programme Board, in addition to key publications/reports identified. The primary concepts and terms identified related to respiratory tract infections (RTIs); upper respiratory tract infections (sinuses and throat) including common cold, sinusitis (sinus infection), pharyngitis/tonsillitis, laryngitis, acute rhinitis, acute rhinosinusitis and acute otitis media; lower respiratory tract infections (airways and lungs) including bronchitis, bronchiolitis, tuberculosis, pneumonia (lung infection), tracheitis and chest infection; lung function test; and antimicrobial resistance (AMR).

The set of systematic searches were performed in November 2021 and no date/period exclusions were applied to the searches (unless otherwise stated). Based on successive screening of sources (i.e. identification of RTI technologies), information was extracted and imported for further data processing.

Information sources used as part of these scans included (but are not limited to):

- ScanMedicine[1],the IO's clinical trial database containing information from 11 registries across the globe (e.g. UK, Europe, USA)
- Regulatory agency sources (e.g. US FDA)
- Publications (including conference outputs)
- MedTech news websites (e.g. Fierce Biotech)
- Commercial websites and reports
- Academic institution webpages
- Patent databases
- NICE medical technologies guidance

Inclusion criteria:

All technological innovations included in the scan had to meet the criteria for a medical technology (e.g. device, diagnostic test, digital or a combination) and be deemed to diagnose, RTIs. All technologies were further classified (see below) and the collated information can be found within the RTI Dataset (Excel file accompanying this report):

Classification of RTI technologies:

- Type of technology (e.g. device, diagnostic test, digital or a combination)
- Clinical target (upper and/ or lower RTI)
- Care setting (e.g. primary care, secondary care, home)
- Target population (sex/age)
- Biological sample type
- Pathogen target (e.g. Bacterial, Fungal or Viral)
- Turnaround time (sample to result)
- Method/Technique (e.g. PCR)
- Biomarker Detected (e.g. CRP and PCT)
- Country of development
- Classification of development stage: Phase 1 (concept stage); Phase 2 (prototype/early-stage research/ preclinical); Phase 3 (technology validated/demonstrated in relevant environment e.g. clinical study); Phase 4 (commercialised i.e. regulatory approved or technology on the market)
- Regulatory status/market authorisation (including list of approved markets)

In addition to these fields, information related to sensitivity/specificity and limit of detection was captured for diagnostic technologies, as well as clinical trial information and published evidence, where available. Furthermore, intelligence relating to funding/investment, development or competition awards and patents that was available during the review of sources, was captured under 'Additional Comments' in the RTI dataset (accompanying Excel file).

Horizon Scanning for SARS-CoV-2 Diagnostic Technologies

The horizon scanning method (including key terms and inclusion criteria) applied to the identification of SARS-CoV-2 diagnostic tests has been published and is included in the methods section of the paper 'COVID-19 Impact on Diagnostic Innovations: Emerging Trends and Implications'[2].

Classification of SARS-CoV-2 technologies:

- Diagnostic Category (molecular assay/immunoassay)
- Development Status (in development/commercialised)
- Type of Molecular Assay or Immunoassay,
- Method/Technique (e.g. PCR, Lateral flow immunoassay, Colloidal gold immunochromatography)
- Home Test Kit/Professional Use
- Turnaround Time (sample to result)
- Biological sample type
- Detects Antibody or Antigen/Pathogen,
- Variant(s) Detected
- Country of Development
- Regulatory status/market authorisation (including list of approved markets)

In addition to these fields, additional information related to sensitivity/specificity (where available from PHE/FIND) is captured in the performance tabs (MDX/IDx).

Results

The Need for Improved Diagnostic Technologies for RTIs

RTIs are caused by a variety of bacterial, viral, and fungal pathogens. RTIs are one of the most common infections and remain a major health burden worldwide, especially amongst older adults and young children. Current laboratory diagnosis (e.g. conventional cultures, PCR) of infections can take 2-3 days. The prevalence of RTI is predicted to continue to rise due to:

1. Empirical antibiotics which may be ineffective and compromise patient outcomes
2. Unnecessary prescribing contributing to the burden of antibiotic resistance
3. The lack of rapid and accurate testing (including difficulties distinguishing viral and bacterial infections),
4. The lack of new antibiotics

Although the treatment choices are substantially different for bacterial and viral infections, the high prevalence of RTIs contribute to a large volume of antibiotic prescription, and are therefore a significant contributor to the growing global issue of AMR.

The rapid development of new and emerging diagnostic interventions for RTI presents an opportunity to strengthen the national AMR strategy, through the adoption of new innovations. Improvements in exiting technologies, along with technological advancements in

diagnostic solutions and clinical biomarkers, have the potential to advance precision in the diagnosis and management of RTIs, reduce inappropriate antibiotic prescribing and thus address the rise in AMR.

Product Pipeline of RTI Diagnostic Innovations

Our horizon scan of primary and secondary sources identified 322 technologies from across 31 countries. Whilst technological developments of RTI innovations are increasingly widespread across the world, our analysis (based on country of development) highlighted that the US (116, 36%), UK (52, 16%), and South Korea (19, 6%) were the top countries for development activity (*Figure 1*). The US was found to develop a wide range of new testing technologies (e.g. CRISPR, biosensors, and microfluidics) alongside existing technologies (e.g. RT-PCR, immunoassays) for the detection of RTIs. Furthermore, the US has a large pipeline of multiplex tests (60) including Hologic's Panther Fusion® Flu A/B/RSV assay, Applied Biocode's Respiratory Pathogen Panel and Luminex's NxTAG® Respiratory Pathogen Panel. Innovations developed in the UK primarily concentrated on pathogen detection for lower RTIs and utilised techniques such as mass spectrometry and Next-Generation Sequencing (NGS).

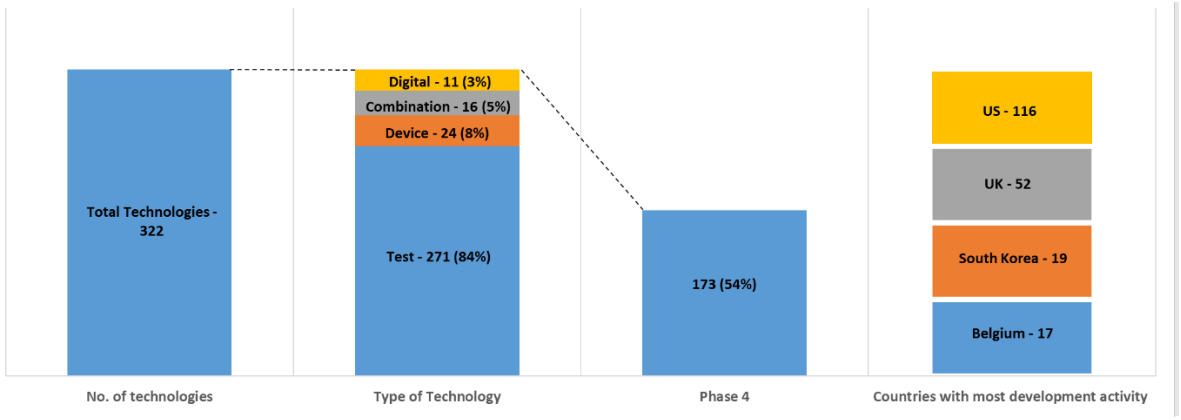

Figure 1. Key Insights into RTI Innovations

322 RTI technological innovations including medical devices, diagnostic tests, digital technologies (or a combination), were identified from across 31 countries. Development activity was largely concentrated in the US (36%) and UK (16%), with a high proportion of products (54%) on the market or ready to market (Phase 4).

All technologies identified as part of this scan have been classified based on their stage of development (Phases 1-4), with Phases 3 and 4 indicative of late/mature stage of development. The majority of the devices were in the mature stage of development, i.e. on or near ready to market, as shown in *Figure 2*. Overall, 140 of the 173 products in Phase 4 (mature phase) have obtained regulatory approval in 1 or more jurisdictions, with 68% of technologies in Phase 4 awarded EU approval (CE Mark).

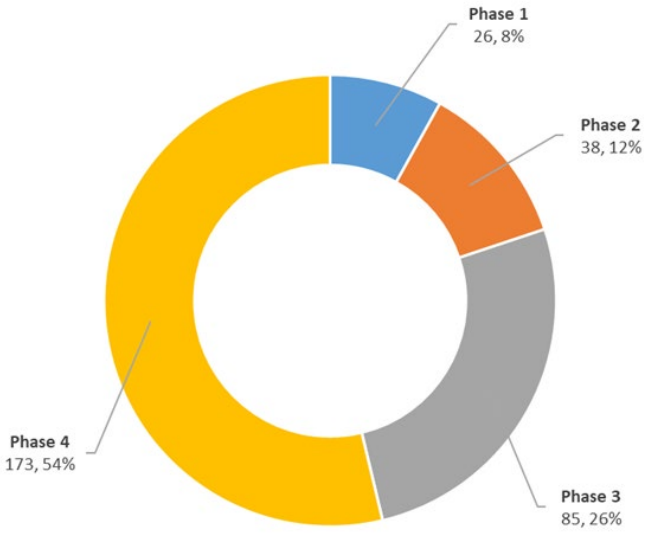

Figure 2. Doughnut chart representing the development stage of RTI technologies
In total, 322 RTI technologies were identified in the Innovations Observatory's scan. The technologies have been classified by stage of development: Phase 1 (i.e. concept) – 26, 8%; Phase 2 (i.e. prototype/early-stage research including preclinical studies) – 38, 12%; Phase 3 (i.e. product validated/demonstrated in relevant environment/clinical study) – 85, 26%; Phase 4 (i.e. product ready to launch/regulatory approved) - 173, 54%.

The vast majority of RTI technologies that were identified were reported to be developed for healthcare professionals use only, however a small proportion of innovative solutions (4) in the pipeline are adapted for use by non-healthcare professionals for use in a community setting. These technologies include digital and diagnostic innovations such as Ellume's Influenza Home Test and the ResAppDx app.

Globally, there remains a growing interest in technologies with the potential to expedite RTI diagnosis results. Most developments to date have been targeted toward decreasing the turnaround time and enhancing automated processing in the clinical laboratory. In total we identified 92 rapid solutions which reported to provide results in 30 minutes or less (sample to result). Of these 17 had a turnaround time of 16-30 minutes, 49 reported to produce results in 6 –15 minutes, whilst 26 reported to provide results in under 5 minutes. The detection strategies implemented in these rapid solutions include traditional lateral flow immunoassays and more novel methods such as CRISPR which has the potential to be developed into a home-based, rapid, portable device utilising simple reagents.
We have also observed the development of new, innovative sampling techniques into technologies. Traditionally, upper respiratory swabs and lower respiratory samples have been used to detect pathogens. These can be difficult to obtain and often uncomfortable for the individual providing them. In the RTI diagnostic pipeline, we identified 10 technologies utilising breath analysis (also known as breathomics), as a rapid, non-invasive diagnostic solution to detect pathogens. 60% of these were for bacterial diagnosis of a lower RTI. IMSPEX Diagnostics Ltd (Wales, UK) have developed BreathSpec, an ultra-sensitivity breath analytical

device that can diagnose bacterial or viral infections through gas chromatography-ion migration spectroscopy. This innovation which has received funding from Horizon 2020 and the Longitude Prize, aims to deliver a low cost, accurate, rapid and easy-to-use point of care test (POCT) for respiratory infections, and thus has the potential to reduce the clinical and financial challenges associated with RTI.

RTI Pipeline Insights: Antimicrobial Susceptibility Testing (AST)

Antimicrobial susceptibility tests (AST) are vital for appropriate management of RTIs, yet only a small number of AST technologies are in development to address this unmet need. This may be due to a number of challenges including the wide range of pathogens that can cause RTIs and the subsequent challenges associated with this, as well as the complexities of designing ASTs. The ASTs identified as part of this scan (e.g. BIOFIRE® FILMARRAY® Pneumonia plus Panel, Xpert® MTB/XDR, Xpert-MTB-RIF) were found to detect genetic markers of resistance using RT-PCR, although the majority appear to target TB infection. Due to the evolving nature of AMR, molecular tests are not always suitable for AST, and a number of AST innovations identified in the pipeline are phenotypic resistance tests, using novel methods such as microfluidics alongside other innovations including the use of NGS with machine learning (DayZero Diagnostics - BacDetect™ with Keynome).

RTI Pipeline Insights: Ventilator Associated Pneumonia (VAP)

Hospital acquired pneumonia (HAP), including ventilator associated pneumonia (VAP), represent a significant challenge, with VAP the leading cause of death in intensive care settings[3]. Due to the high prevalence of RTIs, they contribute to a large volume of antibiotic use, and are therefore a significant contributor to the growing global issue of AMR. Additionally, HAP/VAP are associated with high level of existing antibiotic resistance, therefore becoming increasingly difficult to treat. In total, 7 innovations specifically developed for VAP were identified in the pipeline. Eppendorf Array Technologies have developed VAPChip, a bacterial resistance assay for patients with VAP that has the potential to help enhance appropriate antibiotics prescription. A novel methodology from the University of Manchester, which utilises mass spectrometry for analysis and interpretation of breath for rapid diagnosis of VAP, is currently in 'proof of concept' phase of development. Whilst the FDA-approved electronic nose technology, zNose® from Electronic Sensor Technology, Inc., also uses breath samples and analysis with gas chromatography, and has been validated in the clinical trial, 'Diagnostic Breath Analysis for Detection of Ventilator Acquired Pneumonia (VAP)'.

RTI Pipeline Insights: Tuberculosis (TB)

Tuberculosis (TB) remains a worldwide health threat and leading cause of death due to an infection, despite being a preventable and curable disease[4]. A key factor compounding matters is the growing threat of drug-resistance. The landscape of TB technologies continues to evolve, with a diverse range of technologies identified on the global market. In total, 45 innovations were identified in the development pipeline from across 18 countries. Innovations include rapid pathogen tests (e.g. AccuTell TB Rapid Test Casette, NATLab Tuberculosis Panel, R-DiaTub™)

and drug susceptibility testing (e.g. Xpert® MTB/XDR, Xpert-MTB-RIF, Deeplex Myc-TB). Other TB challenges that developers are seeking to address with advanced diagnostic technology include rapid triage tests (e.g. ScreenTB or TriageTB technology) to identify those with symptoms or risk for TB who require confirmatory testing, non-sputum based tests for active TB, highly predictive latent TB tests to determine those with infection who are at risk of developing active TB disease, and accurate treatment-monitoring tests.

RTI Pipeline Insights: Detection of Bacterial and Viral Infections

Our pipeline scan of technological innovations demonstrated that there was a higher proportion of RTI innovations in development for bacterial targets than for viral (excludes SARS-CoV-2), as shown in *Figure 3 and 4*. In total, 148 innovations were identified covering a wide spectrum of bacterial infections (e.g. M. tuberculosis, B. pertussis. S. pyogenes. L. pneumophila, S. aureus), across different age groups. 83% of the technologies were diagnostic tests with the remainder comprising of medical devices, digital technologies or a combination (*Figure 3*). A closer look at the data revealed that the pipeline of innovations contained a wide range of existing (e.g. PCR, immunoassays and mass spectrometry) and novel technologies (biosensors, CRISPR and microfluidics). It is unclear which technologies, if any, are in use within the NHS at present. There were a small number of early-stage, bacterial innovations utilising artificial intelligence (AI) or machine learning including Tuberculini, BacDetect with Keynome, Strepic, Pattern Bioscience digital culture and UltraPro. These and other emerging and dynamic technologies may bring significant value and opportunities to the NHS in the future for sensitive, rapid and automated diagnostics.

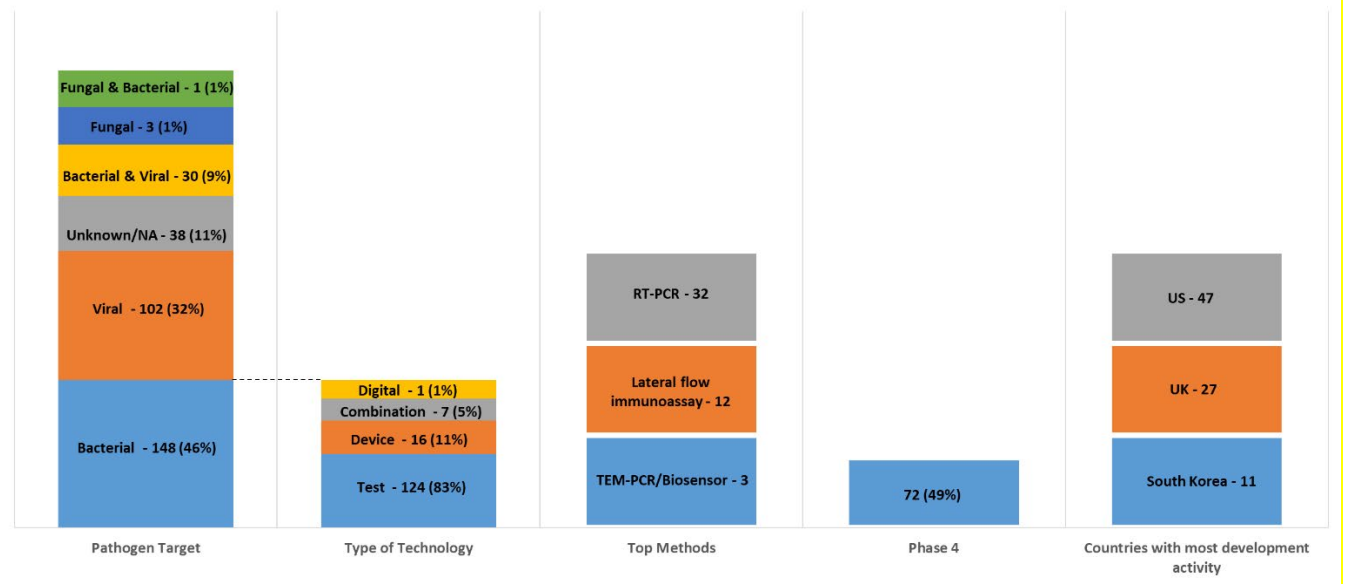

Figure 3. Key Insights into Bacterial Innovations

148 RTI technological innovations for the detection of bacterial pathogens (e.g. B. pertussis, C. pneumoniae, M. tuberculosis, S. pyogenes) including medical devices, diagnostic tests, digital technologies (or a combination). The main analytical method implemented was RT-PCR (22%) and development activity was largely concentrated in the US (32%) and UK (19%).

The pipeline of viral innovations reflected a similar trend to bacterial innovations with RT-PCR and lateral flow immunoassays identified as the most common analytical technique (*Figure 4*), with the latter producing rapid results. New and emerging methods being implemented for a small proportion of innovations include biosensors, nanotechnology and microfluidics. LumiraDx Influenza A/B + RSV Test utilizes rapid microfluidic immunofluorescence techniques for the detection and differentiation of Influenza A, Influenza B and Respiratory Syncytial Virus (RSV). 67 technologies reported to detect more than one viral pathogen; these were mostly duplex of Influenza A and Influenza B, or multiplex with the addition of RSV. Other pathogens that could be differentiated included adenovirus, coronaviruses, parainfluenza and human rhinovirus. Figure 4 demonstrates a large proportion of the technologies were in the mature stage of development (Phase 4).

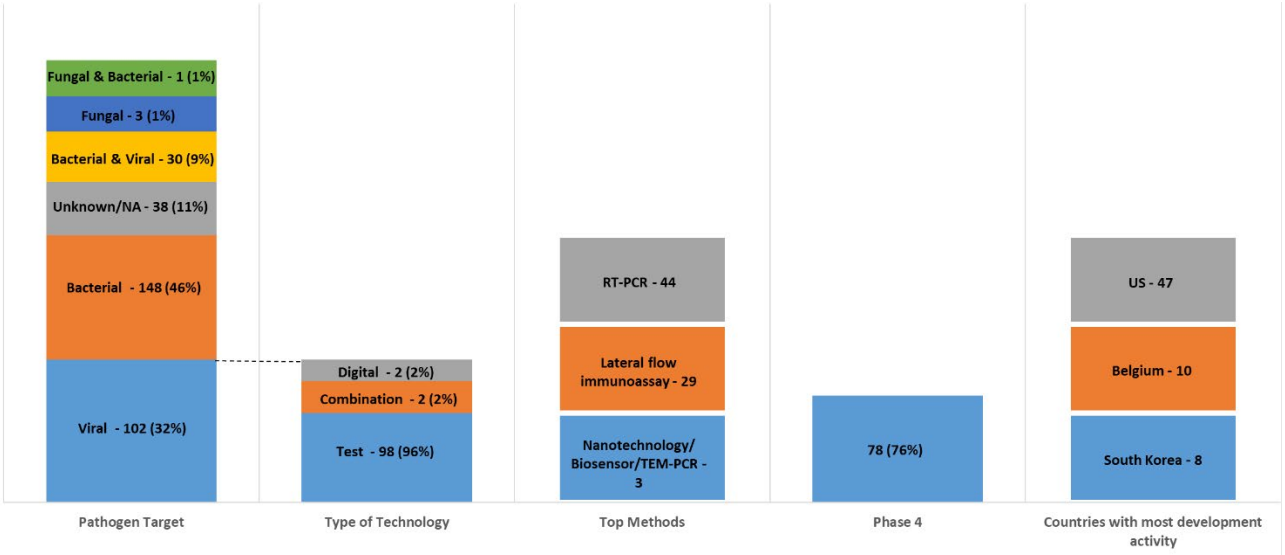

Figure 4. Key Insights into Viral Innovations
102 RTI technological innovations for the detection of viral pathogens (e.g. *RSV*, *Influenza A/B*, *adenovirus)* including diagnostic tests and digital technologies (or a combination), were mainly identified with RT-PCR (43%). Development activity was largely concentrated in the US (46%) and Belgium (10%).

RTI Pipeline Insights: Differential Diagnosis of Bacterial and Viral Infections

With the prevalence of RTIs continuing to increase, combined with antibiotic resistance and the COVID-19 pandemic, there has been an increase in demand for diagnostic innovations that simultaneously detect and distinguish between types of respiratory pathogens. Precise differential diagnosis between bacterial and viral infections is considered highly important to enable appropriate therapy, especially in the context of mixed infections, and to avoid unnecessary antibiotic prescriptions.

Within the RTI pipeline we identified 30 detection technologies which are able to discriminate between viral and bacterial RTIs, with faster turnaround time versus traditional culture methods. Our data analysis revealed that 50% of these are multiplex RT-PCR panels which detect a mix of bacterial and viral pathogens, including 5 tests that utilise Target Enriched Multiplex Polymerase Chain Reaction (TEM-PCR) from Diatherix Laboratories. Our data set

also contains a single mixed pathogen immunoassay, advanced biomarker tests, and a variety of novel technologies that are able to detect across a range of pathogen types. For example, innovations which use NGS (e.g. ONETest, LiDia-SEQ), which can detect across pathogen types including Influenza A/B, RSV, M. pneumoniae and S. aureus, are high-throughput powerful tools which can provide comprehensive information on the pathogen content of clinical samples.

A small number of innovations were identified that utilise biomarker profiles in order to distinguish between viral and bacterial (or mixed pathogen) RTIs. These include the FebriDx® by Lumos Diagnostics, a lateral flow test which detects the presence of C-reactive protein (CRP) and myxovirus resistance protein A (MxA) to differentiate between bacterial and viral RTI. MeMed BV/ImmunoXpert, developed by MeMed with funding and regulatory approval from the EU and US, and validated in multiple clinical trials, utilises TNF-related apoptosis-inducing ligand (TRAIL); inflammatory chemokine interferon-gamma inducible protein of 10 kDa (IP-10) and CRP to differentiate between bacterial and viral RTI. A further example is aQdrop™; aqdrop; a low-cost nanowire diagnostic platform from Sharp Laboratories of Europe Ltd which measures CRP; TNFa; neopterin; IP-10; and β2-microglobulin. Technologies which utilise multiple biomarkers, are advances on single biomarker tests, such as CRP and procalcitonin (PCT), which are well-established with POCT commercially available. Tests which measure CRP / PCT provide an indication of the likelihood of presence of bacterial infection but do not provide information about viral infection, and overall are considered to be less sensitive or specific and insufficient as a standalone diagnostic to guide treatment of RTIs[5]. Human neutrophil lipocalin (HNL) has recently been investigated as a novel biomarker of bacterial infection, with a POCT in phase 2 of development from Ag+ Diagnostics, though early data suggest HNL most useful in combination with other biomarkers such as CRP/PCT. Specifically for Influenza, the University of Texas Dallas are developing a novel test, which measures the biomarker FI6 using Digital Nanobubbles on a Microwell Array Platform, with funding from the US National Institute of Allergy and Infectious Diseases. The improved understanding and application of clinical biomarkers continues to drive the development of rapid and accurate detection technologies that differentiate between bacterial and viral infections. These innovations have the potential to support improved clinical decision making and guide antibiotic use, to reduce the AMR burden.

RTI Pipeline Insights: Innovations for Children and Older Adults

The pipeline of RTI technologies identified were applicable across different age groups (e.g. child, adult and elderly populations). 14 innovations in the pipeline were specifically designed for diagnosis of RTIs in children with one in development by Reinier de Graaf hospital, for diagnosis in neonates. The Paediatric Respiratory Panel developed by Eurofins Diatherix Laboratories LLC, was the only innovation identified that detects more than one pathogen and offers differentiation between bacterial and viral pathogens. The Paediatric Respiratory Panel targets both bacterial (e.g. H. influenzae, S. pneumoniae, M. catarrhalis) and viral (e.g. RSV, Influenza A/B, Human Rhinovirus) pathogens that most frequently cause disease in children. It uses a unique method, TEM-PCR, which is a multiplex amplification platform that delivers

increased sensitivity and specificity whilst simultaneously detecting different pathogens. QuickVue RSV is another technology that has received approval from the US FDA and EU (CE Mark) for diagnosis of RSV, a common childhood respiratory illness.

The digital innovation FLU-ID, developed by the care home provider Cera, may shape the future of the diagnosis and management of flu in older adults. FLU-ID uses AI and machine learning to identify flu faster than traditional methods, enabling carers and nurses to monitor and treat patients swiftly and at home, which may avoid hospitalisation. The technology also has the ability to monitor deterioration in older people's conditions as a result of flu.

Product Pipeline of SARS-CoV-2 Diagnostic Innovations

Since March 2020, the Innovation Observatory has been compiling a diagnostic landscape of all SARS-CoV-2 tests (commercialised/ in development) for the diagnosis of COVID-19. Our comprehensive global dataset (please see accompanying COVID-19 dataset) provides detailed information on the test technique, variant target (if applicable), non-SARS-CoV-2 target (if applicable), country of development, target (e.g. antigen/antibody), sample type and regulatory status. The intelligence has been collated from publicly available sources (including regulatory agencies, MedTech news, journals etc.) and is continually analysed, in order to identify meaningful trends in technological innovations and regulation across geographical regions. To date we have identified 2,679 tests, from across 57 countries (*Figure 5*), covering a diverse range of analytical techniques for the detection of SARS-CoV-2 (antigen) or antibodies against the antigen. Overall, the SARS-CoV-2 diagnostic pipeline is comprised of 1170 molecular assays (*Figure 6*) and 1499 immunoassays (*Figure 7*) and 10 tests remain unclassified, due to no or limited information provided by the developer. The majority of tests either approved or in the development phase for clinical use, detect only SARS-CoV-2 i.e. the original strain (91%); molecular assays – 1017; immunoassays - 1408. In contrast, only a small proportion of tests are in the pipeline that detect SARS-CoV-2 in conjunction with another pathogen (6%); molecular assays – 87; immunoassays - 61. Further analysis reveals that 63 molecular-based and 29 immunological-based products have been developed for the detection of either single or multiple variants of SARS-CoV-2, and 4 tests were identified that detect variant(s) of SARS-CoV-2 alongside other pathogen(s); molecular assays – 3; immunoassays - 1. We have collected and verified the regulatory authorisation data for more than 2000 diagnostic tests from 8 regulatory agencies across the world including the US, Canada, Singapore, Australia, Korea and Brazil. In total, 876 molecular-based and 1249 immunological-based products have obtained regulatory approval in 1 or more jurisdictions, with 47% of products awarded EU approval (CE Mark). Whilst Europe is behind Asia and North America in the scale of diagnostic solutions developed, this region has recorded the highest number of approvals issued (1303).

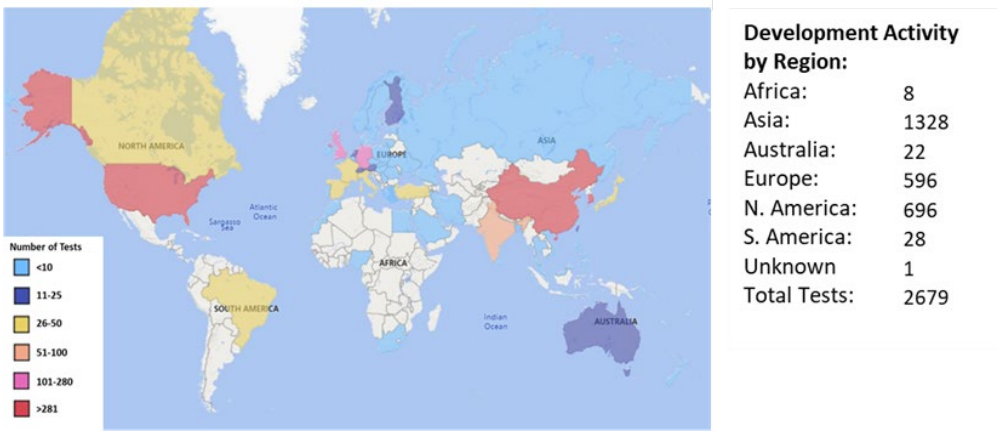

Figure 5. Global SARS-CoV-2 diagnostics landscape
The map provides an overview of the global scale of diagnostic technologies that have been developed for SARS-CoV-2, based on the Innovation Observatory's comprehensive dataset of 2679 diagnostics, either approved or in the development phase for clinical use. China (709) and the United States (638) continue to hold dominant positions in the diagnostic market, accounting for 50% of diagnostics developed. Development activity is concentrated in Asia (50%), North America (26%) and Europe (22%).

SARS-CoV-2 Pipeline Insights: Multiplex Tests

Whilst the majority of SARS-CoV-2 assays developed have been singleplex tests, the ongoing COVID-19 pandemic has resulted in the need to rapidly and accurately detect and distinguish between SARS-CoV-2 and non-SARS-CoV-2 respiratory viruses, which cause similar symptoms as COVID-19. The co-circulation of other respiratory viruses during these unprecedented times has increased the complexity of triaging patients and determining appropriate treatment options. Consequently, this has driven the demand for broad respiratory testing to inform clinical decision making. Our analysis has revealed a marked increase in the development of multiplex tests, which allows for simultaneous analysis of multiple pathogens in a clinical sample. In total, we have identified 154 multiplex tests that have been developed across 16 countries. Currently available multiplex tests, leverage PCR techniques (81) to selectively amplify genes specific to each pathogen of interest. Advancements in analytical techniques (e.g. biosensors, NGS, and lateral flow immunoassays) has also expanded the diagnostic potential of multiplex testing. Randox Laboratories' Viral Respiratory Infection Array (10-plex), Paragon Genomics' CleanPlex® Respiratory Virus Research Panel V2 and Humasis' Humasis COVID-19/Flu Ag Combo Test are assays already available on the market, and many more are currently in development, as a result of the increase in demand for these types of tests worldwide. All multiplex tests detect SARS-CoV-2 in conjunction with other respiratory viruses (154), including Influenza A, B, and RSV. Only one innovation developed by Prestige Diagnostics UK Ltd has been identified which also detects additional non-respiratory targets including HIV and hepatitis (2019-nCoV Neutralising Antibody Device). Multiplex methods are quickly becoming attractive solutions for differentiating between respiratory viruses in contrast to clinical laboratories, due to their broad panels, rapid detection and lower costs. Whilst multiplexed tests show great promise and may help reduce the burden on testing

facilities, further consideration should be given to evaluating the optimal use and performance (e.g. sensitivity and specificity) of these assays, and comparisons made with their singleplex counterparts.

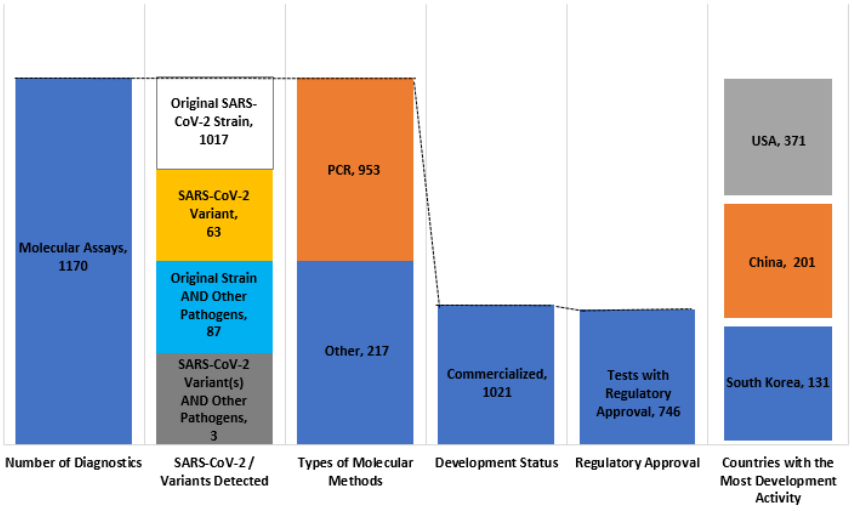

Figure 6. Key Insights into Molecular Assays

1170 molecular-based diagnostic products have been identified for the detection of the original SARS-CoV-2 strain only (1017); original SARS-CoV-2 strain and non-SARS-CoV-2 pathogen(s) (87); variant of SARS-CoV-2 (single/multiple) (63); variants of SARS-CoV-2 and non-SARS-CoV-2 pathogen(s) (3). The most common detection methods implemented for molecular assays was RT-PCR and development activity was strongly concentrated in the US, China and South Korea.

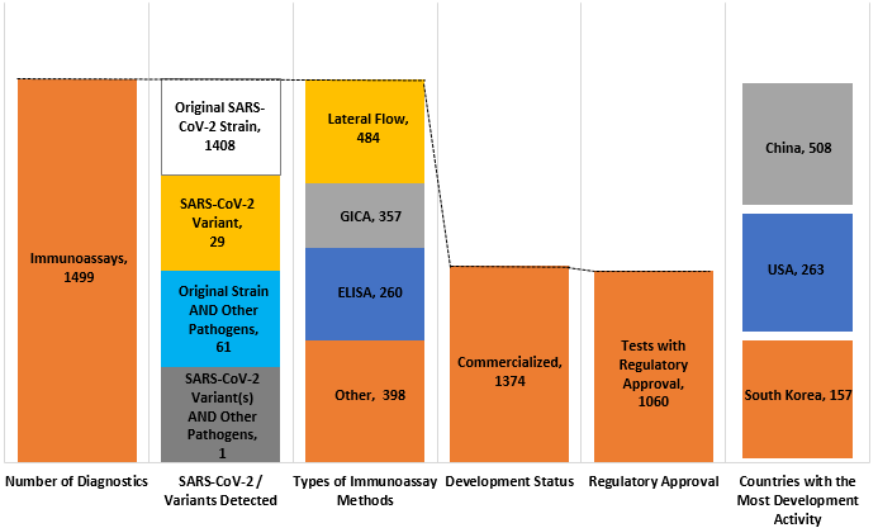

Figure 7. Key Insights into Immunoassays

1499 immunological-based diagnostic products have been identified for the detection of the original SARS-CoV-2 strain only (1408); original SARS-CoV-2 strain and non-SARS-CoV-2 pathogen(s) (61); variant(s) of SARS-CoV-2 (single/multiple) (29); variant(s) of SARS-CoV-2 and non-SARS-CoV-2 pathogen(s) (1). The most common detection methods implemented for immunoassays was Lateral Flow, Colloidal gold immunochromatographic assay (GICA) and enzyme-linked immunosorbent assay (ELISA), and development activity was strongly concentrated in China, the US, and South Korea.

Clinical Trial Landscape

ScanMedicine, the Innovation Observatory's clinical trial tool was utilised to gain access to clinical trial data from 11 registries from across the globe (including the UK, EU, USA, Australia, Japan and Brazil). The clinical trial search excluded trials out of scope e.g. preventative interventions (e.g. masks and vaccines), as well as trials where the evaluation of medical technologies was not the primary intervention (e.g. drug trials).

Figure 8, depicts the changing clinical trial landscape covering trials registered between 2003 and 2021 and provides a holistic perspective of the evolving clinical research ecosystem, including activity by trial start date and the duration of trials to completion. Overall, 123 trials were identified from across 28 countries which meet the inclusion criteria for the scope of this work. One trial (CTRI/2020/04/024681) was omitted from the data visualisation (Figure 8), as no information was provided on the primary study completion date. The EU showed the strongest trial activity (40%), followed by North America (30%) and Asia (21%). On a national level the US (34), UK (17), Japan (6) and South Korea (6) were revealed as the countries with the highest clinical trial activity over the last 20 years.

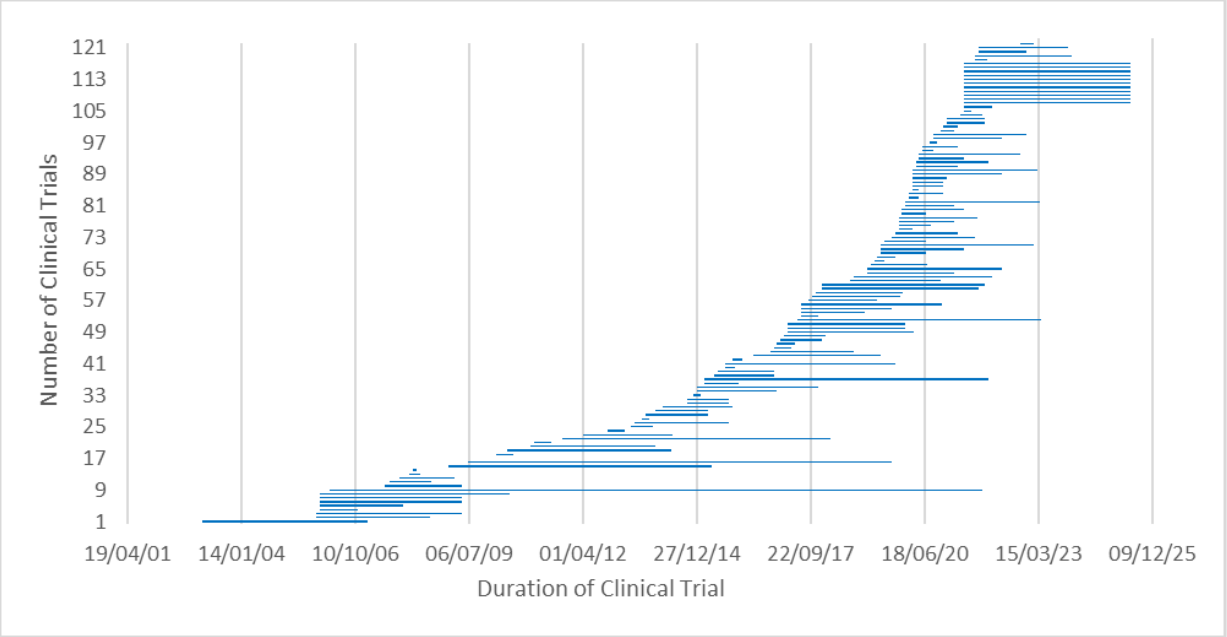

Figure 8. Evolving Clinical Trial Landscape

The clinical trial landscape (activity and duration) for RTI technological innovations.

Within the clinical trial landscape, there was a focus on assessing the accuracy and reliability of diagnostics using established methodologies (e.g. RT-PCR, lateral flow immunoassay) and novel approaches such as AI and breathomics (e.g. breath analysis). In addition, trials concentrated on establishing the potential utility of technologies within a variety of clinical settings such as primary care centres and hospitals. Investigators from Denver Health and Hospital Authority recently completed a study in the US (NCT00938002) (2009 -2019) on critically ill adults at risk for VAP. The study aimed to evaluate the time to diagnosis of VAP,

using a novel flow cell/surface-capture device called Accelerate Pheno® (Accelerate Diagnostics, Inc.). This device which has received US FDA approval, uses multiplexed automated digital microscopy for rapid bacterial identification and antibiotic resistance testing. The results from this trial are yet to be published, however Accelerate Diagnostics have indicated that their technology has the ability to diagnose VAP in under 2 hours, as well as test for antibiotic susceptibility in under 7 hours which is significantly faster than existing conventional methods. Therefore, Accelerate Pheno® is a promising innovation with the potential to reduce delayed and inadequate antimicrobial therapy for patients with VAP. Other applications include the use of mass spectrometry to identify novel biomarkers, microscopy and digital technology. Whilst the pipeline of digital technologies continues to increase, adoption of this type of technology within the health and care system remain at the early stages. Several factors including the pandemic and widespread consumer adoption in general life is causing a substantial and rapid shift in adoption of these technologies in healthcare. In total, 5 digital innovations were identified in this trial landscape and included the use of digital technology for the screening of X-ray images, which has potential to rapidly and efficiently improve diagnosis. For example, an active trial (NCT04666311) is currently evaluating the ability of delf imaging's 'CAD4TB' to accurately detect TB from chest X-rays within 30 seconds.

Trial Insights: Children and Older Adults

Within the older adult populations, there is a high rate of inappropriate antibiotic prescribing, especially amongst older people living in care homes who are particularly susceptible to infections, which can prove fatal without early intervention[6]. Therefore, identifying diagnostics that distinguish viral and bacterial RTIs in these populations is particularly important. In congruence with the RTI product pipeline scan, the RTI technologies identified within the trial landscape were assessed across a wide spectrum of age groups including children, adult and elderly population. Our analysis showed that 9 innovations in the pipeline were specifically designed for diagnosis of RTIs in children. 4 of these studies (TCTR20200414003, NCT00054769, NCT02573623, NCT00512330) evaluated existing methods (e.g. loop-mediated isothermal amplification (LAMP), and RT-PCR) for detection of TB in children in resource limited settings. A study that recently completed in 2019 (NCT03233516) investigated the sensitivity and specificity of several novel POC diagnostic tests alongside the mariPOC® Respi+ for detection of community-acquired pneumonia (CAP) in children. Trial results are currently unavailable, however studies such as these are essential in evaluating the performance of POCTs to ensure the adoption of accurate innovations to help inform clinical decisions and antibiotic therapy.

Our trial landscape only identified one study (NCT04248361) which aimed to evaluate the clinical utility of an RTI diagnostic within the elderly population specifically. The TEM-PCR URI Panel test (Eurofins Diatherix Laboratories, LLC) is a molecular multiplex technology that rapidly distinguishes multiple bacterial and viral pathogens in a single sample, within 8 hours. Although this study is currently suspended due to low enrolment as a result of the COVID-19 pandemic, this TEM-PCR URI Panel test has won several awards including Economic Development Partnership of Alabama (EDPA): Winner of the 2017 Corporate Innovator of the

Year Award. The technique has proved effective in paediatric populations, and has the potential to provide clinicians with essential information early on in the clinical pathway.

Trial Insights: Biomarker Testing

Some of the recently registered clinical trials, are evaluating the utility of novel biomarkers for the detection of TB. One trial (NCT02512939) is currently assessing the diagnostic and prognostic ability of a blood test aiming to identify blood-based biomarkers of immune system activity. Another ongoing trial (NCT05048381) aims to identify a novel miRNA biomarker in the sweat of patients with TB. In addition, the TREND study (NCT03233516), completed in 2019, evaluated the use of MxA as a biomarker for viral versus bacterial CAP in children. Our data analysis shows that clinical trials on novel biomarkers tend to be in the earlier phase of development, and the recent growth in the number of these trials indicates a growing interest in biomarker-based testing.

Patent Landscape

The data from our international patent scan revealed that there were 15,682 patent applications in the field of RTI technological innovations. North America accounted for 60% of patents, followed by Europe (21%) and Asia (6%). The leading countries of patent filings were US (8,787), UK (991) and Germany (619). Our data analysis revealed that 41.5% of patent applications have worldwide patent protection through the World Intellectual Property Organization (WIPO). Since 1997, patents have gradually increased, reaching its peak in 2021 with 2,742 patents (332 more than 2020). The COVID-19 pandemic has not stalled RTI patent applications, perhaps due to the increase demand for development of multiplex tests to identify SARS-CoV-2 alongside common RTIs, such as Influenza A/B and RSV. Leading patent topics included multiplex assays, rapid tests, and microfluidic chips (aka “lab-on-a-chip”). From the patents identified, 26.5% included an indication of TB and primarily focussed on alternative biological samples for identifying this infection, including the use of blood and urine. The trend in the use of alternative biological samples was also reflected across the spectrum of RTI, including George Washington University’s patent for blood biomarkers for respiratory infections, and a patented method to detect immunological markers related to respiratory tract viruses in serum samples by Molecular Diagnostic Technologies, Cytotrend Biotech Engineering and Cmed Technologies. Other patents of interest include Laval University’s probes and primers for identifying common bacterial pathogens and antibiotic resistance genes, National Tsing Hua University’s self-driven microfluidic chip for rapid Influenza A detection, and Chongqing University’s kit for rapidly identifying respiratory tract bacteria, mycoplasma, chlamydia and viruses.

Key Providers

Internationally, industry (small or medium-sized enterprises (SMEs) and large enterprises), research institutions, funding agencies, governments, hospitals and other healthcare organisations continue to play a key role in the development of innovative RTI interventions. Advancements in scientific knowledge and emerging developments in technology have accelerated the development of vital diagnostic tools, thus driving the application of promising

innovations that provide faster results and greater precision for the detection of infections. Our global horizon scan identified over 190 developers from across 31 countries, highlighting the growing impetus to address the critical gaps in the RTI field through the use of diagnostic technologies. Key developers in this area include Quidel, Abbott Diagnostics, Seegene Inc., BioMérieux, Eurofins Diatherix Laboratories, LLC and Diagenode Diagnostics.

The UK has historically been at the centre of global efforts in combatting AMR and RTIs and continues to develop new and emerging diagnostics tools. A total of 47 UK based developers were detected in our dataset, including key developers such as Imperial College London, Newcastle University and Bio-Rad. Imperial College London have a development portfolio of 6 RTI technologies, which is attributed to their multidisciplinary approach to antimicrobial research that involves collaborations with internal and external stakeholders. Similarly, the University of Exeter is developing a novel fluorescence technique that detects antibiotic uptake by bacteria, which has the potential to significantly reduce inappropriate antibiotic prescription and enable the development of more effective antibiotics. The global development pipeline comprised of established technologies (e.g. PCR, lateral flow immunoassays, microassays) alongside new technologies (e.g. AI, machine learning, biosensors) and innovative sampling and analytical techniques (e.g. breath analysis). The development and application of new 'transformational' technologies will continue to shape the global technological landscape and presents a significant opportunity for the NHS (and wider) to consider the clinical, financial, infrastructural, logistical, and organisational provisions to improve preparedness for the potential adoption of these future innovations.

The development of new and emerging RTI diagnostic technologies in healthcare, undoubtedly increases the complexity and challenges of identifying the most potentially promising technologies. From our dataset, we have identified a small selection of technologies with high potential that have attracted significant investment and /or have been shortlisted for development awards and competitions, based on available information at the time of extraction from the information source. Technologies presented in *Table 1* include advances in biomarker-based POCTs for distinguishing viral and bacterial RTIs, multiplex RT-PCR panels of bacterial and viral respiratory pathogens, in addition to genetic markers of antibiotic resistance. We have highlighted novel technologies applied to rapid RTI diagnostics and AST, including breathomics, microfluids, biosensors, digital cell culture and application of morphokinetic cellular analysis (MCA) combined with fluorescence in situ hybridization (FISH).

Table 1. New and emerging RTI technologies with high potential

Developer	Technology	Product Description	Location
Lumos Diagnostics	FebriDx®	FebriDx® is a lateral flow test that can differentiate a viral from bacterial acute respiratory infection. Validated in clinical trial (NCT02018198). Longitude Prize award funded	AUS
MeMed	MeMed BV™ /ImmunoXpert	MeMed BV™/ImmunoXpert™, a POCT which utilizes TRAIL; IP-10 and CRP to differentiate bacterial and viral infection. Validated in clinical trial/s (inc. NCT03011515). Funding from EU and US Department of Defence	Israel
BioMérieux	BIOFIRE® FILMARRAY® Pneumonia plus Panel	The BIOFIRE® FILMARRAY® Pneumonia plus offers RT-PCR detection of 27 bacteria and viruses that cause lower RTIs, as well as for 7 genetic markers of antibiotic resistance. Investigated in clinical trial (NCT04660084).	France
Accelerate Diagnostics	Accelerate Pheno™	The Accelerate Pheno™ system combines FISH and Morphokinetic Cellular Analysis (MCA), to provide antibiotic sensitivity and minimum inhibitory concentration (MIC) in under 7 hours. Investigated in clinical trial (NCT00938002).	US
Pattern Bioscience	Digital Culture™ technology	Digital Culture™ technology for pathogen identification (ID) and antibiotic susceptibility test (AST) results together within four hours. In phase 2 of development with funding from CARB-X and the AMR Diagnostic Challenge Fund.	US
PEAS Institute	Colormetric Test	One step, one minute strip test for a colorimetric detection of a bacterial infection. In stage 2 of development. Longitude Prize award funded.	Sweden
Sense Biodetection Limited	Veros™	Single-Use Instrument-Free Molecular Point-of-Care Diagnostic Test for Influenza and RSV. In phase 2 of development. Innovate UK grant funded.	UK
Imspex Medical	BreathSpec ®	A rapid, non-invasive, cost-effective, analytical device for bacterial or viral infection diagnosis through ultra-high sensitivity breath analysis. In phase 3 of development. Horizon 2020 funded and Longitude Prize funded.	UK
Imperial College London	Trisilix	The 'lab on a chip' which performs a miniature version of the polymerase chain reaction (PCR) on the spot has potential to be embedded in hand-held device that can give results in minutes and be used at-home for detection of bacterial and viral	UK

		pathogens. In phase 1 of development with support / funding from UKRI and Wellcome Trust	
University of Plymouth	Biosensor-based pathogen identification and AST	Low cost, rapid (5 minutes), point of care nucleic acid-based biosensor assays for pathogen detection and AST. In phase 2 of development. Longitude Prize funded.	UK
University of Exeter	Single-cell microfluidics	Microfluid technology applied to a phenotypic resistance test for AST, in phase 2 of development (not currently RTI specific).	UK

Other Innovations of Potential Interest

The scope of the RTI scan is especially focussed upon rapid diagnostics to guide antibiotic use and AMR best practice, however, other innovations of relevance were captured in the RTI dataset file in the 'Other Innovations of Interest tab'. These include technologies in development for the prevention of VAP, wearable technology for remote monitoring, stratification of risk / prognosis in RTI, and clinical decision support systems (CDSS).

Our dataset includes a small number of innovations designed for prevention of VAP. The Venner PneuX(TM) System is a novel ventilation tube and cuff pressure monitor from Qualitech Healthcare Ltd, whilst a noble metal alloy endotracheal tubing developed at the Bucharest Clinical Emergency Hospital has results available from a randomized controlled trial (ACTRN12618002055280). Other innovations that target infection prevention include two electronic stethoscope that enable remote and wireless auscultation to prevent infection of healthcare professionals. Arsanis Biosciences have received EU funding for phase 1 research around a novel biomarker which is able to predict patients at risk of S. aureus induced VAP, which may be used to aid prevention.

We identified a number of technologies aimed at remote monitoring and prediction of risk / prognosis. This includes the E4 Wristband, a wearable device designed to detect acute viral RTI and predict infection severity before symptom onset, in stage 1 of development from Emphatica & Duke University. The EarlySense system by EarlySense, validated in clinical trial (NCT03010774) utilises a sensor placed under patients' mattress to monitor vital signs and alert healthcare system if patient begins to deteriorate. Imperial College London have developed a wearable sensor for RTI, which has been assessed in trials of patients infected with influenza A (NCT04204993). Innovations targeted at remote monitoring may be particularly valuable in the context of plans within the NHS for delivery of Primary Care led Infection Assessment Hubs with associated virtual wards, including for management of patients with RTI, UTI and skin infections.

There were innovations in our dataset which meet the need for CDSS; an intervention that has been shown to reduce antibiotic prescribing for RTIs. Two CDSS innovations developed by the ZonMW research institute in the Netherlands, and the University of Sydney, are designed to be used as a diagnostic tool and to assess risk, including of RTI, in paediatric patients presenting

with fever. The iCPR, a CDSS from NYU Langone Health, is currently being validated in the clinical trial, 'Decreasing Antibiotic Prescribing in Acute Respiratory Infections Through Nurse Driven Clinical Decision Support' (NCT04255303). Meanwhile, University of Oxford have developed the RAPID clinical risk prediction score; a low-cost prognosis prediction score to identify patients at risk of poor outcomes from RTI.

Of note to antibiotic use within RTI, the dataset contains two technologies that can monitor patients' antibiotic levels. An antibiotic chip utilising microfluids technology that can detect antibiotic levels through breath, in stage 3 of development from the University of Freiburg in Germany. A Therapeutic Drug Monitoring (TDM) system in phase 1 of development by the Molecular Warehouse and University of Surrey, is a blood test which measures antibiotic levels so that patients receive the correct dosages of antibiotics for a given infection, ensuring rapid treatment of the infection and avoidance of antibiotic resistance.

Funding Landscape

Our scan of funding databases identified 92 projects (active and completed) between 2003 and 2021. Our analysis revealed that the international funding landscape is being transformed by advancements in technological innovations. Since 2003, there has been a steady growth in funding invested in research and development focused on technological innovations for detection of RTIs. In 2020 there was a notable peak in funding allocated to the innovations for RTI, which was likely driven by high levels of investment during the pandemic (*Figure 9*). The majority of projects identified by the funding scan were research grants, and collaborative research and development projects with a focus on technological innovations for the detection of RTI causing pathogens.

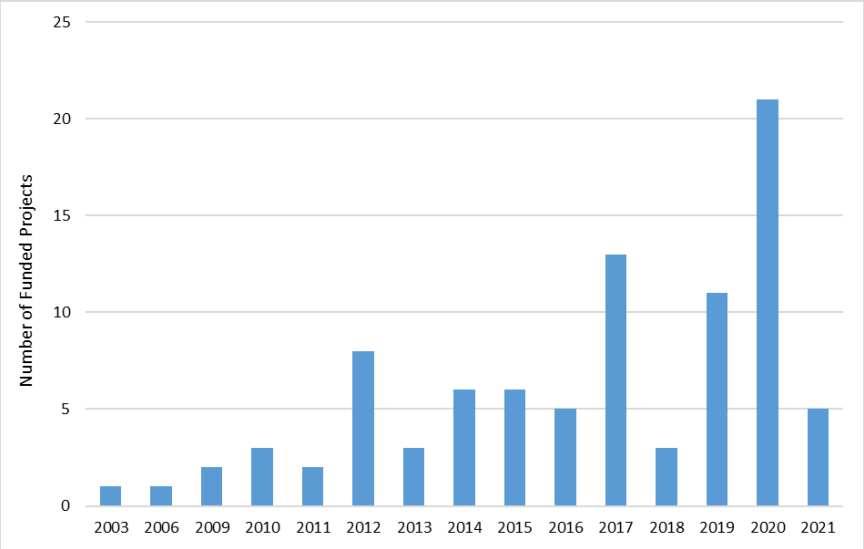

Figure 9. Global trends in funded research project (by start year) with a focus on technological innovations for the detection of RTIs.

There has been a steady increase in the number of approved funding applications in the field of RTI focused on the detection of infections (2003-2021), with a peak in the number of projects detected in 2020 (21).

On an international scale, the US funded the highest number of research projects (40, 43%), followed by UK (23, 25%). Overall, both the US (40%) and EU (40%) awarded the largest proportion of funding for research and innovation globally (*Figure 10*). Other countries such as Australia and Switzerland also contributed to the funding landscape of RTI MedTech innovations. At a national level, our data analysis revealed a total of 23 research projects funded by multiple funding bodies including the Medical Research Council (MRC) (37%, £6,762,582), the National Institute for Health Research (NIHR) (26%, £4,860,393) and Innovate UK (17%, £3,110,721) (Figure 11).

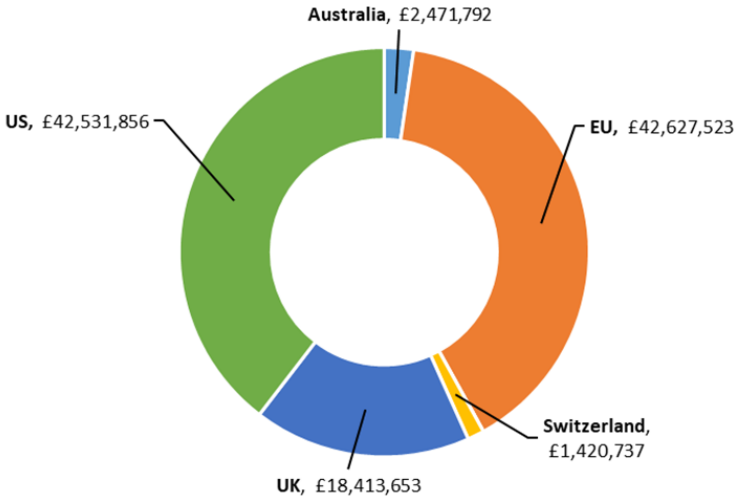

Figure 10. Doughnut chart showing the international funding landscape
Total funding identified by the Innovation Observatory across Australia (2%), EU (40%), UK (17%), US (40%) and Switzerland (1%).

The funding landscape is primarily comprised of innovations such as POCTs, biosensors and breathomics. BreathSpec is an innovative portable breath sampler that has recently received funding from the European Commission (EC) as part of the Horizon 2020 funding (EC, €2,367,647,50), as it is a non-invasive POCT with the ability to identify different characteristics, in order to generate algorithms that can differentiate between bacterial and viral infections. This technology has the potential to reduce the prescription of antibiotics for RTI's by over 30%. Another innovative project funded by the EC and co-ordinated by University College London (UCL) in the UK is the RID-RTI project (€5,997,737). This multiplex RT-PCR assay rapidly identifies various types of pneumonia in under two hours, in comparison to conventional methods which can take up to 2 days, and result in patients receiving inadequate or adequate empirical antibiotic therapy. In the US, an optoelectronic immuno-sensing device has received funding from the National Science Foundation (NSF, £199,999) for the diagnosis of viral pathogens including SARS-CoV-2. This battery powered, portable diagnostic tool, integrates biosensors and photodetection to rapidly detect viral pathogens and their structural proteins with the use of a disposable microfluidic chip. The scan for funding activities and investment also identified innovations that focus on the diagnosis of TB, which is an unmet need in RTI diagnostics. The research project Tuberculini is an example of a novel

research project funded by the EC (€50,000) for the development of an in-vitro diagnostic test that tackles the diagnosis of multidrug-resistant TB and also provides an appropriate therapy plan within 24 to 48 hours from sample collection. This platform uses machine learning algorithms and NGS to diagnose and determine antibiotic resistance and susceptibility for a larger number of antibiotics (12), in comparison to already marketed tests detecting 1-5 antibiotics.

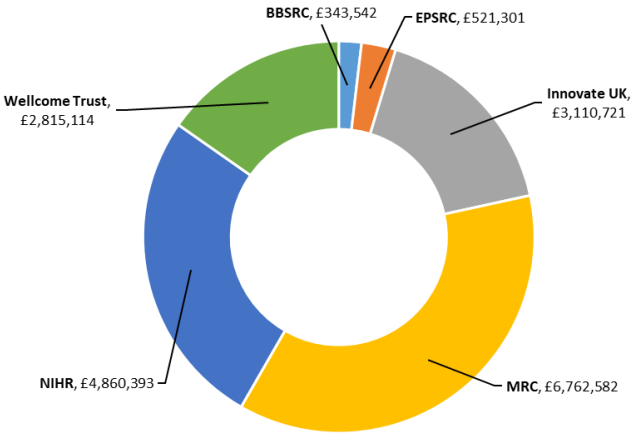

Figure 11. Doughnut chat showing the UK funding landscape
Landscape of UK funding providers, with leading funders: MRC (37%), NIHR (26%) and Innovate UK (17%).

Conclusion

Our global horizon scan provides NHSE/I and the AMR Programme board (and wider) with opportunities for discovering new and emerging diagnostic technologies. These diagnostics interventions could help to address the overuse of antibiotics, by ensuring that critical results are received and acted on in a timely manner.

As the pipeline of technologies continually evolves, it is important that these innovations address unmet diagnostic needs such as rapid and accurate detection (including drug-resistant infections). 5 key areas of unmet need which diagnostic innovations are being implemented to address include:

1. Rapid and accurate diagnosis of infections
2. Biomarker testing
3. Differential diagnosis of bacterial and viral pathogens
4. Antibiotic susceptibility testing (AST)
5. Rapid and accurate identification of ventilator-associated pneumonia (VAP)

Overall, our scan has demonstrated that a high proportion of technologies identified within the RTI and SARS-CoV-2 pipeline address 1 or more of these key areas of unmet need. The majority of innovations developed focused on the rapid detection of infections (e.g. POCTs), which will allow for confirmation of diagnoses earlier on in the clinical pathway, leading to a reduction in inappropriate uses of antibiotics. As healthcare expands into the community,

POCTs that deliver results quickly and accurately promise to radically change infection detection and treatment. Despite their potential value, the clinical performance and cost-effectiveness of these technologies should be fully explored across clinical settings, to identify those that will provide the NHS the greatest value with regard to their impact on RTI and AMR. New opportunities exist for efficient diagnostic technologies based on their biomarker target using a diverse range of techniques and biological samples. The discovery of new biomarkers (e.g. MxA, miRNA for TB) are showing promising potential for the detection of the causative pathogens and disease severity. Furthermore, the development of technologies with a combination of established and new biomarkers for multiplex analysis is creating new opportunities for high predictive performance, to discriminate between bacterial and viral infection and thus guide appropriate therapy.

Diagnostic innovations will continue to play a critical role in providing appropriate care for RTIs. Whilst new technologies continue to improve our ability to accurately and rapidly diagnose many infections and tackle the overuse of antibiotics, the need for additional advancements is increasingly recognised. Furthermore, gaps remain in the clinical evaluation of the performance of technologies and the widespread adoption of high performing innovations. In addition, consideration should also be given to clinical outcomes and impact on clinical workflows, as different technologies might prove to be optimal for different clinical settings, outcomes or based on other specific measurements or priorities. Overall, our analysis shows a high number of promising innovations in the development pipeline which have the potential to help optimise the use of hospital resources and improve patient outcomes, by reducing unnecessary antibiotic prescriptions and enhancing appropriate therapy.

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