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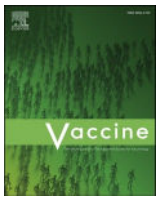

Vaccines and AMR: An analysis of the funding landscape for human bacterial vaccines in low-and middle-income countries

Catherine Fleck-Vidal [a], Anna Doubell [b], Christiane Gerke [a], Usha Lamichhane [c], Lesley Ogilvie [c], Ralf Sudbrak [c], Jerome H. Kim [d,e], T. Anh Wartel [a], Laura Plant [a,*]

[a] International Vaccine Institute, Europe Regional Office, Stockholm, Sweden
[b] Impact Global Health, Sydney, Australia
[c] Global AMR R&D Hub, Berlin, Germany
[d] International Vaccine Institute, Seoul, South Korea
[e] College of Natural Sciences, Seoul National University, South Korea

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ABSTRACT

Background: Vaccines are critical tools to prevent the emergence and spread of antimicrobial resistance (AMR) through prevention of infection and reduction of subsequent antibiotic use. Since AMR is a critical issue disproportionately affecting Low- and Middle- Income Countries (LMICs), we examined investments in research and development for bacterial vaccines with a focus on LMIC-driven research.

Methods: Publicly available funding data on projects active from January 2007 to 15 January 2024 from the G-FINDER and Global AMR R&D Hub databases were analysed. The investment into human bacterial vaccine R&D was analysed to identify the recipients and geographic distribution of funding provided directly from funders and through intermediary organisations.

Findings: Global funding of vaccine R&D for bacterial pathogens in this dataset totals 4.50 billion USD, with the majority of funding directed towards *M. tuberculosis* and *S. pneumoniae.* Most funding was received by organisations in North America and Europe, with Asia, Africa, and Central/South America collectively receiving less than 20 % of the total funding. Philanthropic and intermediary organisations, particularly Product Development Partnerships (PDPs), emerge as critical players in mobilising and coordinating resources for bacterial vaccine R&D in LMICs.

Conclusion: Comprehensive and transparent reporting is needed to accurately assess funding to LMICs. Nevertheless, the current analysis shows that PDPs and intermediary funders are pivotal in ensuring investments reach LMIC product developers. Data gaps remain for critical bacterial pathogens on WHO's AMR priority pathogen list.

1. Background

Antimicrobial Resistance (AMR) is a major global threat to human health, undermining decades of progress in the treatment of infectious diseases. [1] Currently estimated to be associated with the loss of 5 million lives annually, AMR is projected to cause up to 10 million deaths annually by 2050. [1,2] The most recent estimates show that in 2050, 1.91 million annual deaths will be directly attributable to an infection with an antimicrobial resistant pathogen, and 8.22 million yearly deaths will be associated with AMR through the contribution of an antimicrobial resistant pathogen. [2] The UN General Assembly has acknowledged AMR as a critical issue disproportionately affecting Low- and Middle-Income Countries (LMICs). [3] In these countries, healthcare systems are often under-resourced, and populations are more vulnerable to infectious diseases, making the burden of drug-resistant infections especially severe. [4]

Existing and new antibiotics alone are insufficient to curb the spread and reduce mortality associated with AMR. Antibiotic development is highly resource-intensive and time-consuming, and in settings where access to healthcare services and antimicrobial treatments may be limited, vaccines offer a cost-effective and sustainable solution to mitigate the transmission of resistant bacteria within communities. [5] In

* Corresponding author at: International Vaccine Institute, Europe Regional Office, Berzelius väg 8, 171 65 Stockholm, Sweden.
E-mail address: Laura.Plant@ivi.int (L. Plant).

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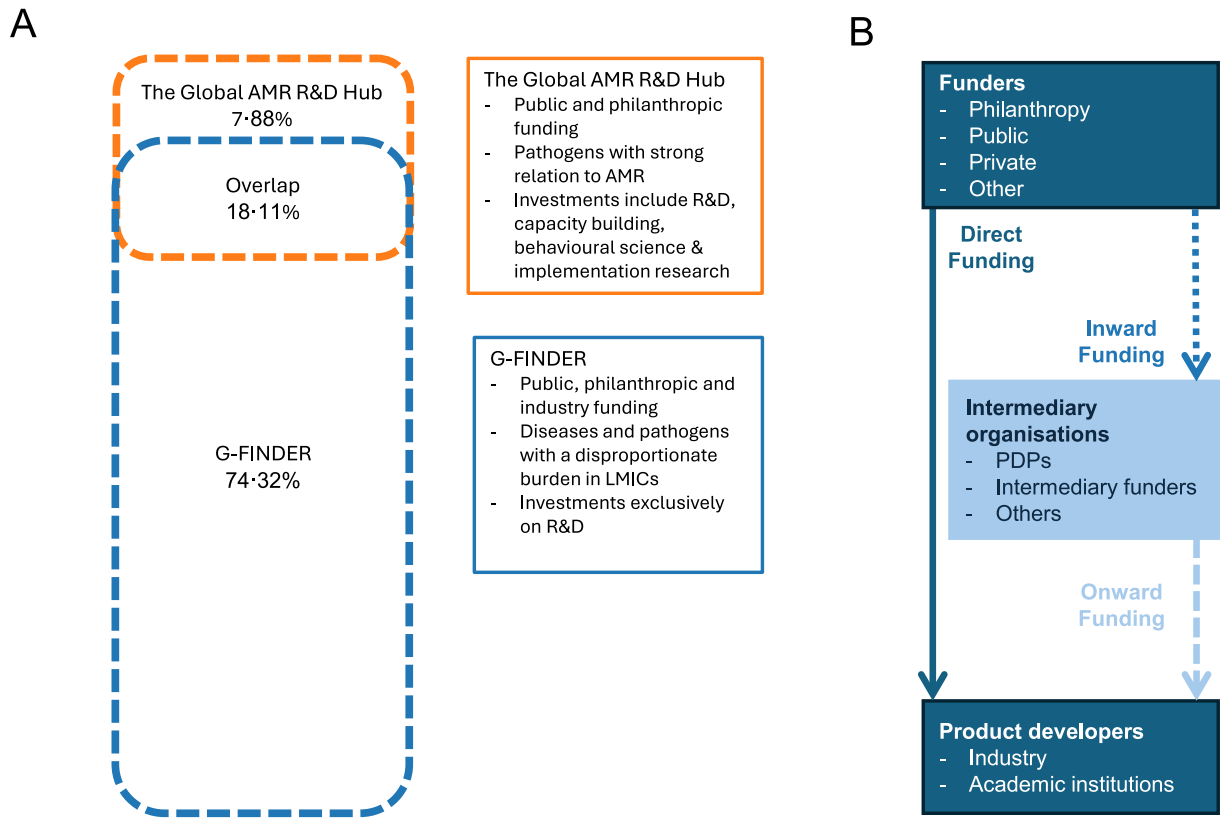

Fig. 1. Data used to assess R&D funding into human vaccines against bacterial pathogens. (A) Distribution of data of included in the dataset from the Global AMR R&D Hub and G-FINDER databases. (B) Direct and onward funding streams from funders to product developers, including the role of intermediary organisations. For this analysis, the data represents end recipients of direct and onward funding ("product developers").

2024, the WHO released an updated list of priority bacterial pathogens of public health importance to guide research, development, and strategies to prevent and control AMR. [6]. A recent analysis showed that approximately 18 % of AMR-associated deaths in LMICs could be prevented by expanding the coverage of existing vaccines that reduce antibiotic consumption or directly prevent AMR infections, combined with the implementation of infection prevention and control (IPC) and water, sanitation, and hygiene (WASH) interventions. [4,7] Vaccination has emerged as a vital approach to mitigate AMR by preventing infections, significantly reducing the need for antibiotics at the population level, and impeding the spread of bacterial resistance. [8] Notably, bacterial vaccines as well as vaccines against viral and parasitic infections such as influenza, respiratory syncytial virus, and malaria play a role in minimising antibiotic misuse and overuse. [4,8]

Despite vaccines being one of the most cost-effective global health interventions, funding for vaccines to combat AMR is low compared to investment into new therapeutic products. [9] A recent analysis of the global AMR research and development (R&D) investment by research area using data from the Global AMR R&D Hub for 2017–2022 revealed that public funding into therapeutics has increased while vaccine funding has declined. [10] While not all bacterial infections contribute to the development and spread of AMR, the prevention of bacterial infections by vaccination is important to mitigate the AMR threat. The landscape of vaccine investment for bacterial pathogens is complex and this analysis provides a comprehensive overview of the funders and recipients of investments into R&D with primary a focus on LMIC-driven research.

2. Methods

2.1. Data sources

The G-FINDER [11] and Global AMR R&D Hub [9] databases constitute the most comprehensive publicly available source of information on global funding for bacterial vaccine and AMR R&D. The data included in this analysis was downloaded from the Global AMR R&D Hub and G-FINDER websites and constitutes funding for bacterial vaccine R&D from January 2007 to January 15, 2024.

G-FINDER offers comprehensive data on global annual investment into R&D of new products to prevent, diagnose, control, or cure health challenges that primarily affect LMICs (including neglected diseases, emerging infectious diseases, and sexual and reproductive health). The G-FINDER dataset focuses on emerging and neglected infectious diseases. The data is collected via an annual survey of funders, intermediary organisations, and product developers, including industry, active in global health R&D. Only investment directed towards basic research and human health-focused product development is included in the dataset, excluding behavioural intervention and implementation research. G-FINDER tracks direct funding (from primary funding organisations to product developers), inward funding (from funders to intermediary organisations), and onward funding (from intermediary organisations to product developers). To determine a grant's recipient, G-FINDER records the headquarters location of the product developers or the university to which the researchers are affiliated. A significant amount of data in G-FINDER is allocated to non-specified recipients, so additional, aggregated information was received to designate recipient countries for improved analysis. The total direct funding for R&D in G-FINDER for all products and all pathogens totalled 63.54 billion USD. Between 2007 and 2023, funding towards bacterial vaccines accounted for 7 % of all products reported. Of this funding, 17.99 % (742.06

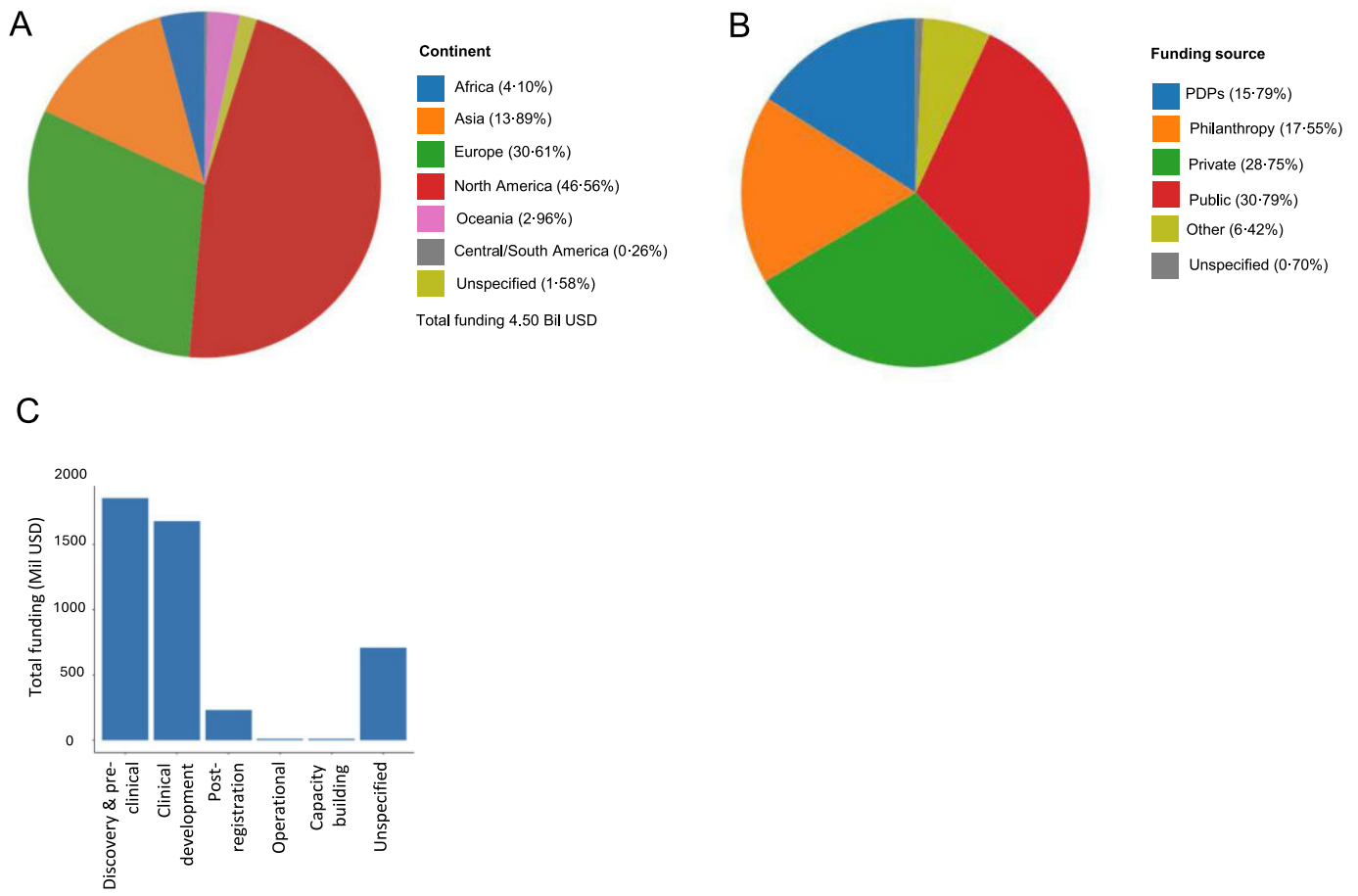

Fig. 2. Funding for R&D of human vaccines against bacterial pathogens. (A) Distribution of funding by recipient continent. (B) Sources of funding for bacterial vaccine R&D. (C) Distribution of funding by the different stages of vaccine R&D.

million USD) was received by vaccine developers in LMICs.

The Global AMR R&D Hub, established in 2018, gathers data on public and philanthropic funding for research projects active as of January 1, 2017, and those initiated afterward, excluding industry funding. The database's Dynamic Dashboard captures publicly disclosed direct investments and onward funding to research institutions and product developers via funding distributors or intermediaries. Data is collected through targeted searches in relevant funder databases as well as the Dimensions database [12], using standard search terms and specific keywords developed with expert input. [13] To be included in the dashboard, projects must focus explicitly on AMR-related R&D across the One Health continuum. Funding on any AMR-related disease is included (with relevance for both HICs & LMICs), and for co-funded projects, each funder's contribution is considered a separate investment. Data were filtered for projects including "Human" as sector, "Vaccines" as research area, and "Bacteria" as infectious agent. To determine annual investment, the total budget of each project is distributed proportionally over their duration. The total funding recorded in the database is 13.67 billion USD as of August 22nd, 2024, without filtering for vaccines or the human sector. Between 2017 and 2024, the Global AMR R&D Hub reports that funding towards the discovery and development of human bacterial vaccines constituted 7 % of overall funding. Of this funding, 3.35 % (12.49 million USD) was received by vaccine developers in LMICs.

2.2. Selection Criteria

The authors recognise the complex ecosystem contributing to increasing AMR and the significant impact of the animal and environmental sectors and diseases caused by viruses, fungi, and parasites. However, this analysis focused on human vaccines against bacterial pathogens. Investments without specified bacterial pathogens were excluded. The selection criteria included investments made since 2007 (with the caveat that the Global AMR R&D Hub Dynamic Dashboard only includes investments from 2017 onwards) (1) on vaccines against bacterial pathogens, (2) in the human sector, and (3) in research areas that comprise vaccine-related projects.

2.3. Data management

The data collected from both databases (Fig. 1A) were cleaned and analysed using R. To prevent double reporting in the G-FINDER data, we utilised G-FINDER's distinction, separating direct inward funding (funders to intermediaries) from onward funding (intermediaries to product developers/end-recipients) (Fig. 1B). The Global AMR R&D Hub's onward funding represents 4.41 % of all onward funding and was merged with the onward funding data from G-FINDER. In this analysis, onward funding constitutes a subset of overall funding. Duplicate data in the source material were identified by manual comparison and verified duplicate entries were removed. The datasets utilised in the analysis are (1) merged total end-recipient funding data (direct and onward) and, (2) merged end-recipient data from onward funding.

New variables were created to capture information on continents, recipient country classifications (high-income vs. low- and middle-income according to the World Bank classifications, accessed August 2024 [14]), type of funder (philanthropic, public, private, or other), type of funding (domestic vs. non-domestic) and intermediary type – if relevant (Product Development Partnership, intermediary funder, or

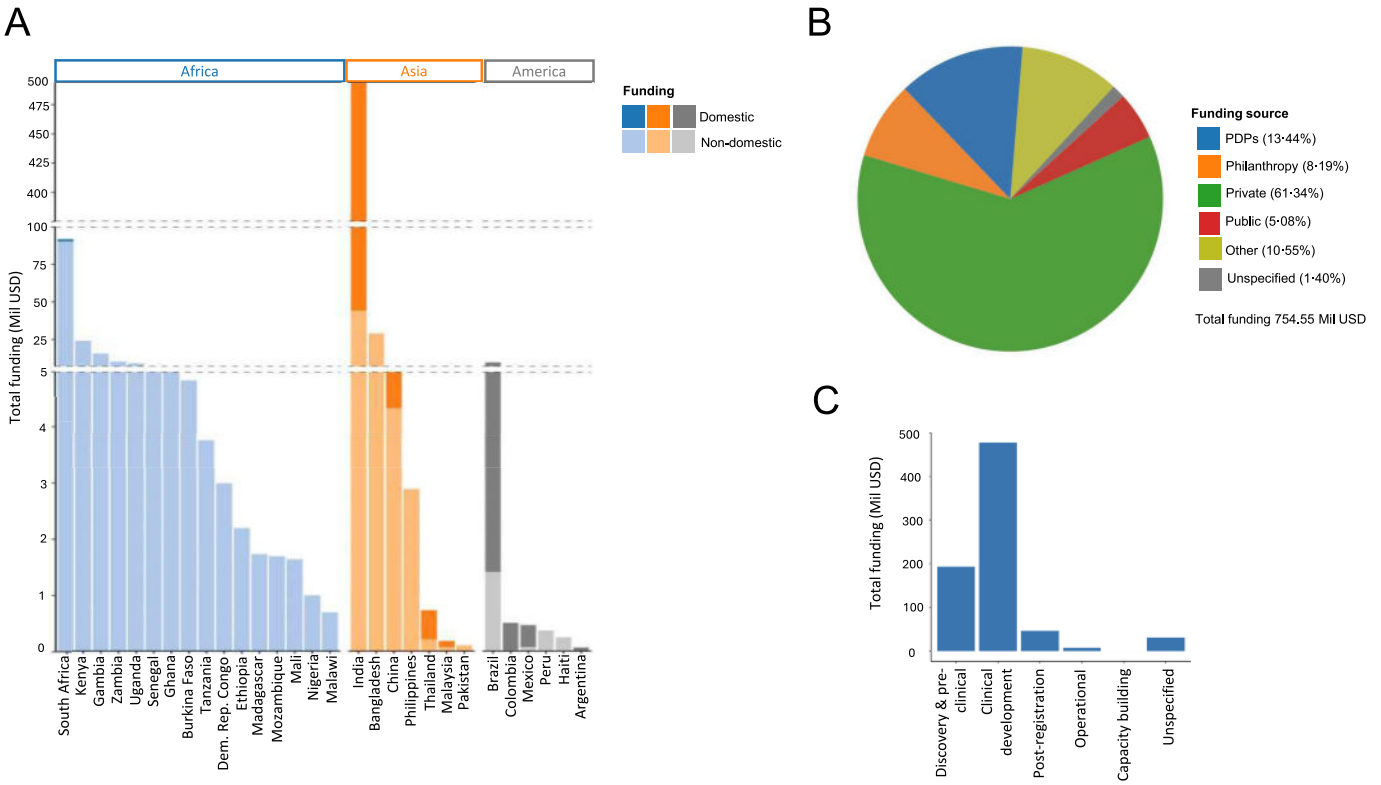

Fig. 3. Funding for R&D of human vaccines against bacterial pathogens allocated to LMICs. (A) Amount of funding for bacterial vaccine R&D received by LMIC recipient country. (B) Sources of funding for bacterial vaccine R&D allocated to LMICs. (C) Distribution of funding received by LMIC by the different stages of vaccine R&D.

other). Intermediary organisations receive funding directly from a research funder and allocate it to product developers through funding programs, sub-awards, or sub-contracts. The types of organisations included in onward funding are PDPs, specialised intermediary funders, and other intermediary organisations that do not fall into these two categories. Although PDPs are themselves product developers, they have emerged as essential intermediary organisations allocating funding as onward funding to product developers, particularly in LMICs.

R&D stages were classified as discovery and pre-clinical, clinical development, operational, capacity building, and unspecified, according to their designation in the databases. Philanthropic, public, or private funders were classified according to their self-designation. Funders not fitting into these three categories were classified as Other, including those funded by multiple funding sources, such as Gavi, Combating Antibiotic-Resistant Bacteria Biopharmaceutical Accelerator (CARB-X), and the European and Developing Countries Clinical Trials Partnership (EDCTP).

3. Results

3.1. Distribution of R&D funding for bacterial vaccines

Since 2007, the global publicly disclosed funding for human vaccine R&D against bacterial pathogens is 4.50 billion USD. The allocation of the funding between continents (Fig. 2A) shows that product developers in North America received the largest amount (46.56 %), followed by Europe (30.61 %), Asia (13.89 %), and Africa (4.10 %). Product developers in Oceania received a total of 133.17 million USD (2.96 %), and the lowest direct allocation is observed for R&D in Central/South America with a combined funding of 11.72 million USD (0.26 %). The geographical distribution was not specified for 71.14 million USD (1.58 %). Recipients received most funding from public (30.79 %) and private (28.75 %) funding sources, with significant contributions from philanthropy (17.55 %) and PDPs (15.79 %) (Fig. 2B). Most funding was allocated to discovery and preclinical research (41.27 %), followed by clinical development (37.31 %) (Fig. 2C).

3.2. R&D funding allocated to LMICs

Funding allocated to LMICs represented 16.78 % of total R&D funding, or 754.55 million USD. South Africa, India, and Brazil emerged as the countries from Africa, Asia, and Central/South America that received the most funding (Fig. 3A). Notably, 68.86 % of the funding to LMICs was towards bacterial vaccine R&D in India, and 91.47 % of this funding came from domestic sources. Other LMICs that reported domestic funding contributions were Brazil, South Africa, Mexico, Argentina, Malaysia, and Thailand. When excluding Indian domestic funding, the amount received by LMICs decreases to 5.91 % of global funding. External, non-domestic funding to LMICs represented 35.24 % of all funding to LMICs, totalling 265.93 million USD. This non-domestic funding was primarily allocated to countries in Sub-Saharan Africa, followed by countries in Asia and Central/ South America. The private sector was the largest funder of LMIC R&D, accounting for 61.34 % of the total, although this funding was primarily directed to India (99.93 %) (Fig. 3B). A significant portion of funding to LMICs also flowed via PDPs (13.44 %), followed by other funders (10.55 %), philanthropy (8.19 %), and government funders (5.08 %). These funders included the EDCTP (9.35 % of total LMIC funding), the Bill & Melinda Gates Foundation (BMGF) (7.38 %), and the PDPs PATH (4.70 %), Aeras (4.68 %), and the International Vaccine Institute (IVI) (3.04 %) (data not shown). Most LMIC funding was directed towards early-stage research and clinical development (Fig. 3C).

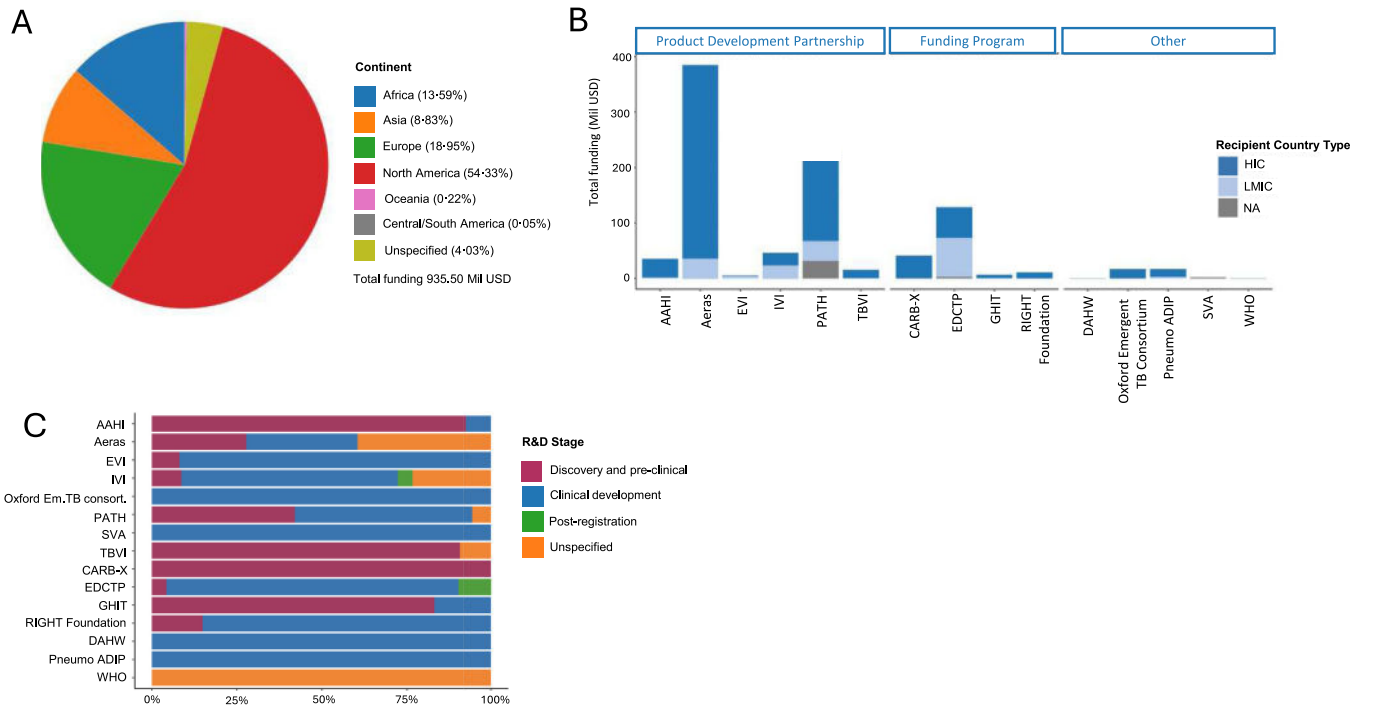

Fig. 4. Onward funding through intermediary organisations. (A) Geographical distribution of funding provided to product developers by intermediary organisations. (B) Amount of funding provided by individual intermediary organisations to product developers by recipient country type. (C) Distribution of funding per R&D stage provided by the individual intermediary organisations to product developers.

3.3. *Contribution of intermediary organisations to R&D funding*

Intermediary organisations allocated 935.50 million USD to product developers (Fig. 4A). Recipients in North America received the largest contribution (54.33 %), followed by Europe (18.95 %), Africa (13.59 %), Asia (8.83 %), Oceania (0.22 %), and lastly Central/South America (0.05 %). Funding without a geographical designation represents 4.03 % of the onward funding. Intermediary organisations allocated a larger proportion of funding to LMICs (18.59 %) than direct funders (12.36 %). LMIC recipients of this type of funding were predominantly based in Sub-Saharan Africa and Asia, with a smaller amount directed to end-recipients in Central/South America. South Africa, India, and Brazil emerged as the countries receiving the most funding from intermediary organisations.

Onward funding to product developers flowed through PDPs (78.10 %), but intermediary funders (20.05 %) and other intermediaries (1.85

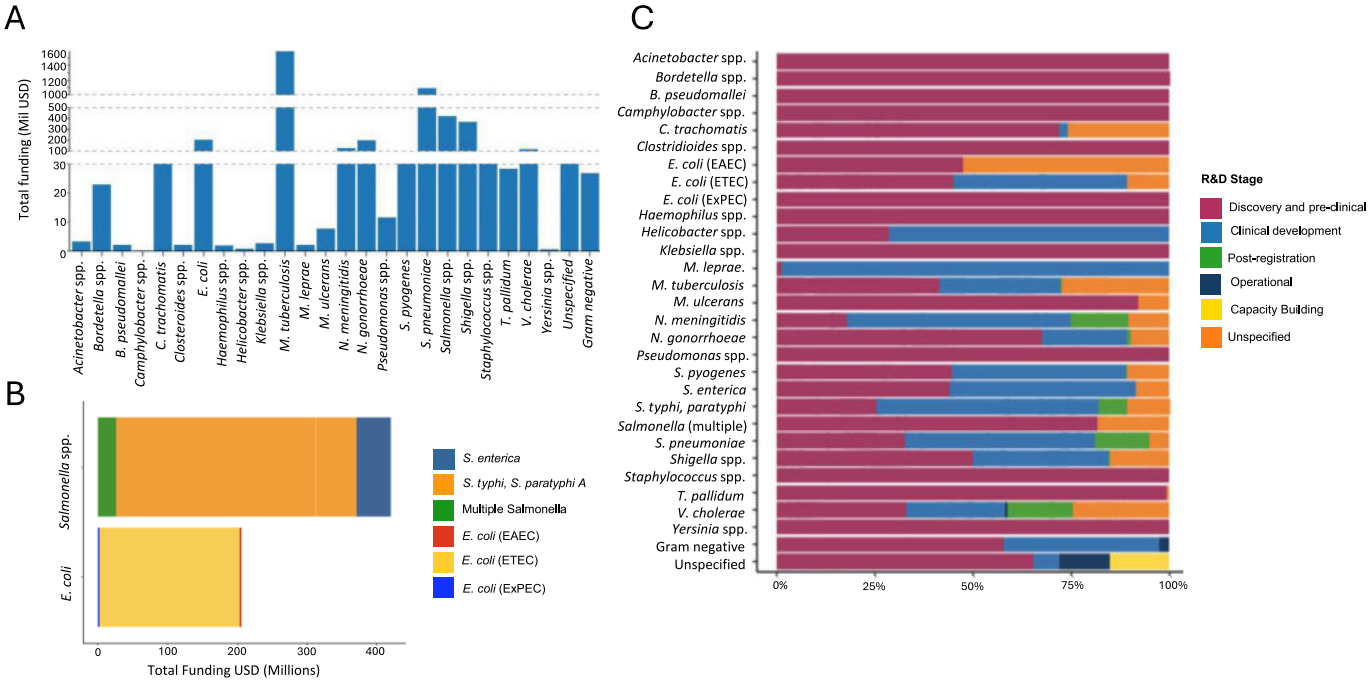

Fig. 5. Funding of vaccine R&D against bacterial pathogens (A) Funding of vaccines against specific bacterial pathogens. (B) Distribution of vaccine R&D funding for individual bacterial pathogens per R&D stage. (C) Division of direct R&D funding for *Salmonella* spp. and *E. coli* spp.

Table 1
Funding by type of funding source and pathogen. Data in the table represents the top 10 pathogens reported in the data set. Data are given as percentages of total amount received for vaccine R&D for individual pathogens. Private funding is based only on data from G-FINDER.

Funding source	% of Total	*M. tuberculosis* (%)	*S. pneumoniae* (%)	*S. typhi, S. paratyphi A* (%)	*Shigella* spp. (%)	*N. meningitidis* (%)	*Entero-toxigenic E. coli* (%)	*V. cholerae* (%)	*N. gonorrhoeae* (%)	*S. pyogenes* (%)	*C. trachomatis* (%)	Remaining pathogens (%)
Private	28.75	19.44	43.05	15.69	7.50	6.24	1.84	0.05	4.09	0.27	0.50	0.03
PDPs	15.79	59.07	15.60	2.51	5.73	6.28	6.51	3.89	NA	0.15	NA	0.26
Public	30.79	39.79	7.68	3.72	7.98	2.76	6.65	4.59	5.24	4.20	3.76	13.63
Philanthropy	17.55	36.18	30.69	7.08	13.22	3.78	1.53	2.68	0.29	1.05	0.08	3.42
Other	6.42	29.36	19.28	6.09	5.38	1.37	6.46	2.04	0.52	5.47	NA	24.03
Unspecified	0.70	3.04	62.46	0.42	NA	14.91	NA	6.29	NA	0.12	NA	8.74
Total investment	4497.21	1592.89 (35.42 %)	1091.49 (24.27 %)	345.83 (7.69 %)	367.92 (8.18 %)	202.01 (4.49 %)	200.87 (4.46 %)	121.03 (2.69 %)	129.15 (2.87 %)	86.12 (1.93 %)	59.22 (1.32 %)	299.83 (6.68 %)
Mil USD (% of total)												

%) also allocated funding to product developers (data not shown). Aeras provided the greatest amount of onward funding, followed by PATH and the EDCTP (Fig. 4B). The EDCTP was the most significant contributor of intermediary funding for LMICs (70.53 million USD), followed by the PDPs PATH (35.44 million USD), Aeras (35.30 million USD), IVI (22.92 million USD), and the European Vaccine Initiative (EVI) (4.23 million USD).

Intermediary organisations funded various R&D stages: the Access to Advanced Health Institute (AAHI), TBVI, CARB-X and GHIT mainly focused on the discovery and preclinical development, while IVI, the Oxford Emergent TB Consortium, PATH, SVA, EDCTP, the RIGHT Foundation, and DAHW had a more significant focus on clinical development (Fig. 4C). Most onward funding by R&D stage was allocated to clinical development (32.76 %), followed by discovery and preclinical research (31.22 %).

3.4. Funding allocation by pathogen

Most R&D funding for bacterial vaccines was directed towards R&D for vaccines against *M. tuberculosis* (35.42 %) and *S. pneumoniae* (24.27%) (Fig. 5A). Vaccines against *Salmonella* spp. (9.28 %), *Shigella* spp. (8.18 %), and *N. meningitidis* (4.49 %) have received moderate funding (200–500 million USD). Vaccines for pathogens such as *V. cholerae* (2.69 %), *N. gonorrhoeae* (2.87 %), and *C. trachomatis* (1.32 %) have each received funding below 150 million USD. Among *Salmonella* spp. vaccine funding, the largest share was directed towards *S. typhi* and *S. paratyphi A*, with funding of around 345 million USD (Fig. 5B). In comparison, research on Non-typhoidal *S. enterica* (NTS) and multiple *Salmonella* infections each received around 50 million USD. Among *E. coli* vaccine funding, research on Enterotoxigenic *E. coli* (ETEC) received close to 200 million USD (4.46%), with lower amounts allocated to Enteroaggregative *E. coli* (EAEC) (0.05 %) and Extraintestinal pathogenic *E. coli* (ExPEC) (0.04 %). In addition to *M. tuberculosis* and *S. pneumoniae*, the private sector significantly funded vaccine R&D on *S. typhi* and *S. paratyphi A* (15.69 %) (Table 1). *Shigella* spp. received 5.13 % of funding from all sources. In contrast, *V. cholerae, N. gonorrhoeae,* and ETEC received under 7 % of funding by type of funding source (excluding unspecified funders). *N. gonorrhoeae* was generally funded by private and public funders, while PDPs and public funders most often funded ETEC. In Africa, North America, Central/South America, and Europe, most funding was directed towards vaccines for *M. tuberculosis* (Supplementary Table 1). Vaccine funding was allocated to the discovery and preclinical stage for most pathogens (Fig. 5C). However, for vaccines against *N. meningitidis*, *S. pyogenes*, *Salmonella* spp., *S. pneumoniae*, *Shigella* spp. and *V. cholerae*, substantial amounts were also directed towards clinical development stages.

3.5. Onward funding allocation by pathogen

Most onward funding through intermediary organisations was directed towards combating *M. tuberculosis* (57.46 %), *S. pneumoniae* (14.98 %), *E. coli* (6.93 %), *N. meningitidis* (5.12 %), *Shigella* spp. (5.00 %), *S. typhi, S. paratyphi A* (3.68 %), and *V. cholerae* (3.21 %) (Fig. 6A). In comparison to the results for overall funding, onward funding showed a higher focus on clinical development (Fig. 6B).

3.6. Vaccine investment for bacterial pathogens over time

Generally, R&D investments for bacterial vaccines remained stable from 2007-2024 (Fig. 7A). Until 2015, investments were primarily focused on pathogens with existing vaccine coverage, but since 2015, an increase in investment into R&D for pathogens without vaccine coverage can be observed. This increase has been accompanied by a decreased investment in R&D against pathogens with existing vaccine coverage. An analysis of investment into vaccines for the WHO priority pathogens reveals that the highest investment is directed towards

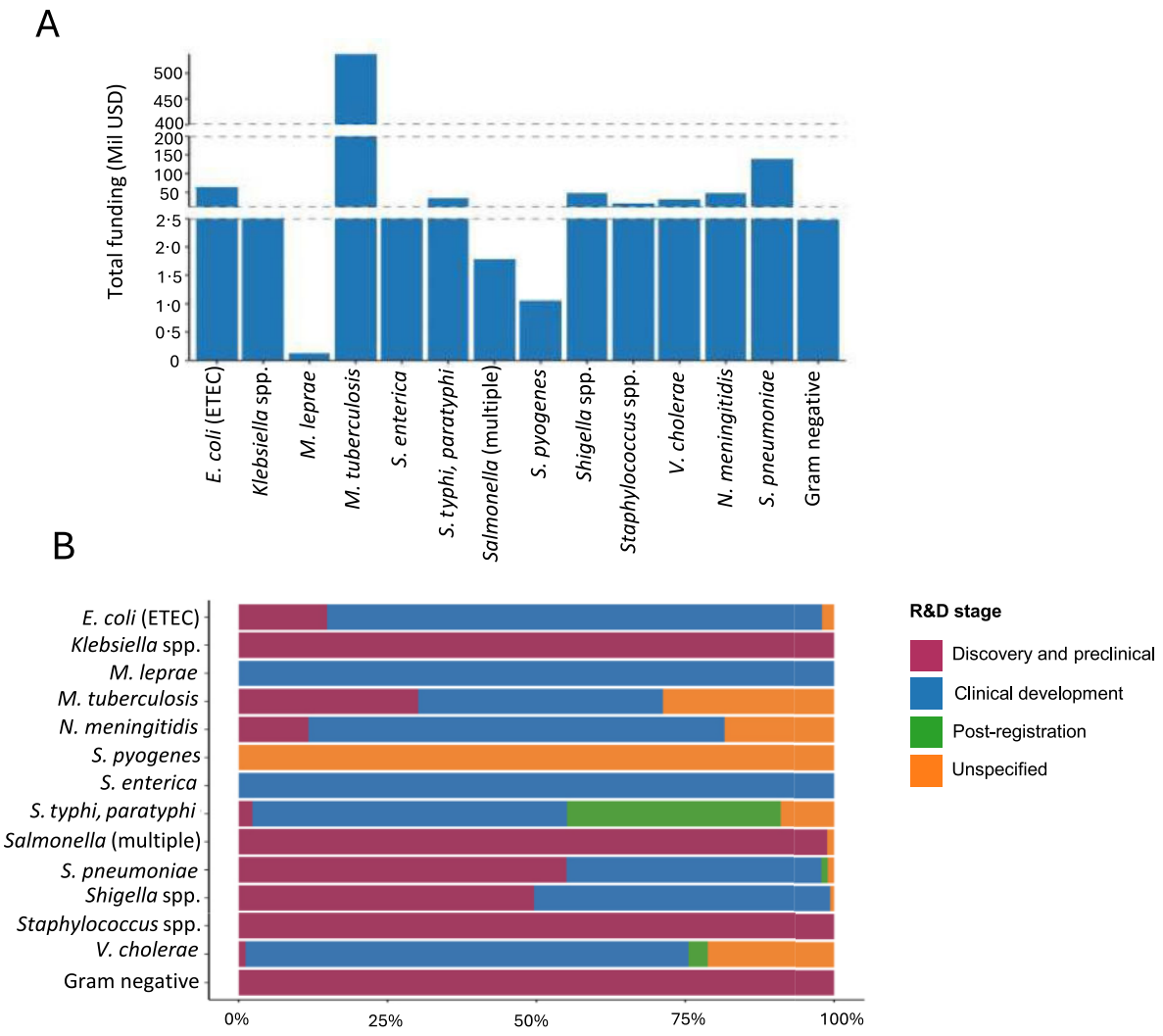

Fig. 6. Funding distributed by intermediary organisations towards vaccine R&D against bacterial pathogens (A) Funding distributed by intermediary organisations towards vaccine R&D for individual bacterial pathogens. (B) R&D stage of bacterial vaccine funding provided by intermediary organisations.

M. tuberculosis and *S. pneumoniae (data not shown)*. An assessment of remaining priority pathogens (Fig. 7B) shows an increase in funding for vaccines against *N. gonorrhoeae* and *Shigella* spp., whileinvestment into the development of vaccines for NTS, *Haemophilus* spp., *Staphylococcus* spp., and *Acinetobacter* spp. was relatively lower.

4. Discussion

Vaccines for bacterial pathogens play a crucial role in preventing life-threatening infections and, as such, the emergence of resistance from antimicrobial use. In recent years, some funders have launched calls specifically directed towards developing vaccines to mitigate AMR. These funders include CARB-X, the BMGF, the Biomedical Advanced Research and Development Authority (BARDA) of the United States government, Wellcome, and the Health Emergency Preparedness and Response Authority (HERA) of the European Union. The current analysis provides a comprehensive overview of the funding distribution for vaccine R&D for bacterial pathogens, irrespective of whether the projects have been specifically assigned to impact AMR.

Over 90 % of the available data focuses on R&D for vaccines targeting neglected diseases in LMICs, reflecting G-FINDER's inclusion criteria. The Global AMR R&D Hub collects data exclusively on public and philanthropic funding, excluding industry contributions. Recognising the distinct criteria of the databases, they collectively represent the most comprehensive available data on global R&D funding.

The analysis reveals a clear imbalance in funding distribution. North America and Europe receive the majority of funding, while Asia, Africa, and Central/South America collectively account for less than 20 % of the total investment. Notably, Sub-Saharan Africa, South Asia, and Latin America—regions with the highest estimated mortality rates attributable to and associated with antimicrobial resistance (AMR) [15]—experience a significant disparity in funding, most pronounced in Central/South America.

In both databases, location of the primary grant recipient or headquarters of the product developer determines "recipient country". Funders and intermediary organisations provide information about their primary investment allocations; however, sub-contract/partner recipient information is not provided. In addition, while the methodology used here accurately identified the primary locations of funding recipients, it did not allow insight into where the research is conducted. As a result of these limitations, contributions to end-recipients in LMICs may be significantly underreported, masking their involvement in global R&D efforts.

In the current analysis, India emerged as a striking example of how strong local investment can positively impact an R&D system. India's emphasis on domestic funding for vaccine R&D, workforce development, and entrepreneurship has resulted in the launch of successful companies, such as Biological E and the Serum Institute of India, the

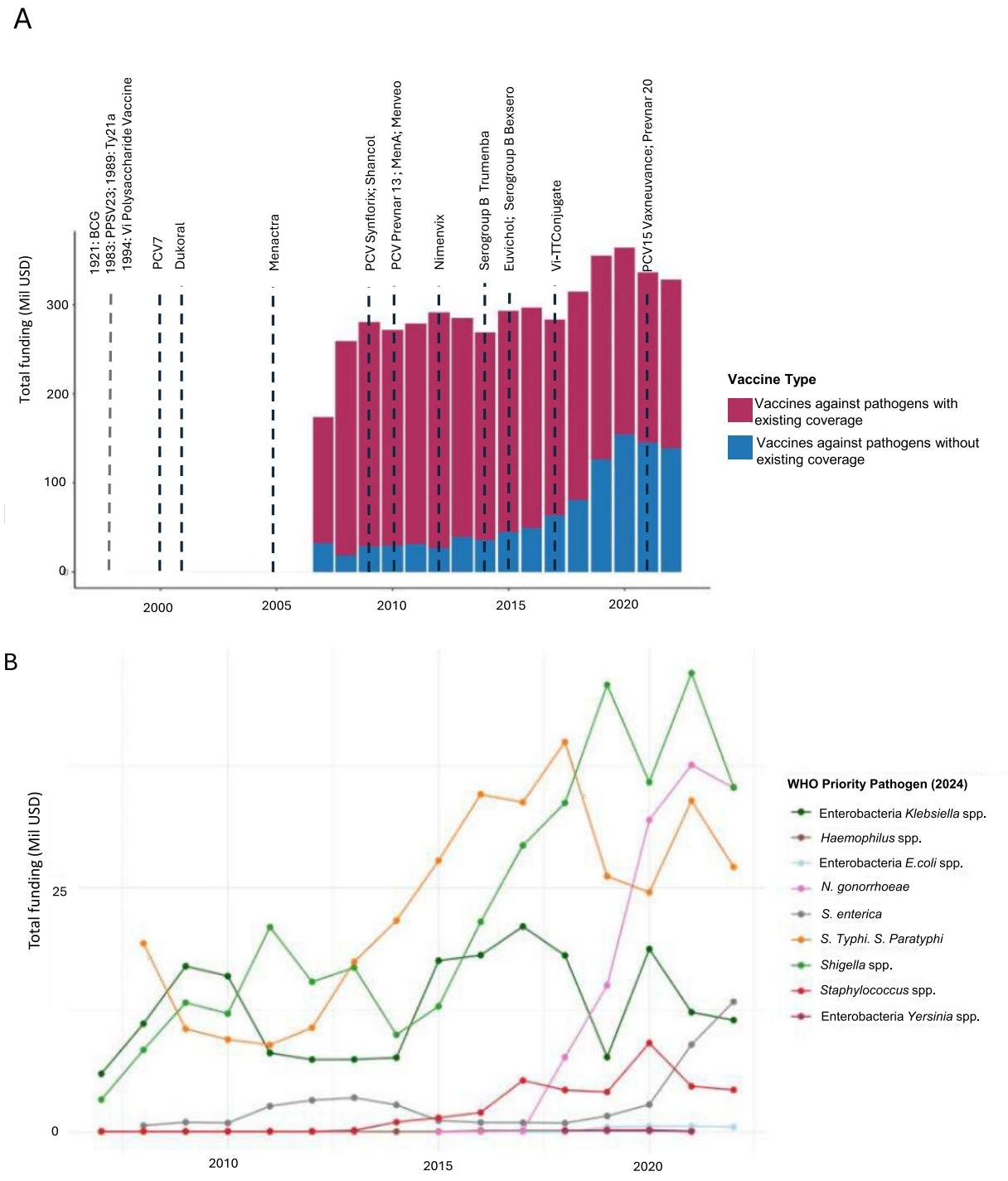

Fig. 7. Temporal analysis of human vaccine R&D investments. (A) Investment into vaccines against pathogens with and without existing vaccine coverage (B) Vaccine R&D investments into the WHO priority pathogens. *E. coli* includes Enterotoxigenic *E. coli*, Enteroaggregative *E. coli* and Extraintestinal pathogenic *E. coli*. *M. tuberculosis* and *S. pneumoniae* have been excluded to enable visibility of investment into remaining WHO priority pathogens.

world's largest manufacturer of vaccines. [16] India's progress, mainly since the COVID-19 pandemic, is a model for other LMICs. [16] Over the past two decades, BRICS countries have made significant advances in science, technology, and innovation, highlighted by the launch of the BRICS Vaccine R&D Centre in India in 2022. [17] India, South Africa, and Brazil have emerged as the top funding recipients in their regions. However, there are substantial differences in funding among these countries: India's domestic investments account for nearly 70 % of all financing towards LMICs, South Africa received 12 %, and Brazil just over 1 %.

While a shift in funding to LMICs may not be immediate, the COVID-19 pandemic has highlighted the necessity for end-to-end projects to support local vaccine manufacturing. Such investments, include, but are not limited to, vaccine R&D. Initiatives, such as the African Union's Platform for Harmonized African Health Products Manufacturing (PHAHM), aim to increase vaccine production in Africa to cover 60 % of regional needs by 2040. [18] The needs of LMICs should be a key consideration in the strategies of external vaccine funders and product developers. Apart from India, LMICs primarily receive funding from non-domestic sources, with philanthropy and intermediary

organisations being the main funding channels. The key organisations that allocate funding to LMICs include the EDCTP, the BMGF, and the PDPs PATH, Aeras (acquired by IAVI), and IVI. Although only representing about 21 % of the total funding, the additional funding that flows through intermediary organisations increases the proportion of funding allocated to LMICs, in line with their mission to support R&D in low-resource settings.

PDPs emerged in the late 1990s and early 2000s [19] and facilitate product development to tackle poverty-related diseases and health threats underserved by traditional markets. [20] By building successful partnerships between the public, private, academic, and philanthropic sectors, PDPs can develop products at a total cost below that of the private sector. [20] A recent report suggests that approximately 2.4 billion people have benefitted from more than 60 new health technologies introduced by PDPs. [21] An analysis from 2010, also utilizing G-FINDER data, confirmed their essential role in the R&D landscape for neglected diseases. [19] Among intermediary organisations, PDPs play a significant role in channelling investments in bacterial vaccine R&D to LMICs, accounting for 13.44 % of the total funding to LMICs. This number rises to 38.13 % when excluding domestic funding sources (mainly Indian investment). Given their proven track record and significant impact in LMICs, PDPs will remain pivotal for vaccine research addressing AMR.

Within the period of this analysis, funding for bacterial vaccines has predominantly targeted discovery and preclinical research, while onward funding primarily focused on clinical development, highlighting the critical role of intermediary organisations in driving vaccine R&D to clinical development and beyond. Funding has been concentrated on vaccines against *M. tuberculosis* and *S. pneumoniae*. Over time, there has also been an observable shift towards developing vaccines for pathogens that lack coverage, concurring with the registration of improved vaccines for *V. cholerae*, *N. meningitidis*, and *S. typhi*. An increase in investment against *N. gonorrhoeae* can also be seen since 2017/2018, coinciding with the emergence of XDR *N. gonorrhoeae*. [22]

The WHO priority bacterial pathogens are divided into critical, high, and medium categories. [6] While most of the pathogens on this list are represented in this dataset, *Enterococcus faecium* and Group B *Streptococcus* are absent. Projects for vaccine R&D of *Acinetobacter baumannii*, *Klebsiella pneumoniae*, and *Haemophilus influenzae* received less than 10 million USD since 2007, collectively representing 0.20 % of total funding. Of note, *Helicobacter pylori* and *Campylobacter* spp., listed as high priority on the WHO 2017 list of priority AMR pathogens, have received limited funding (collectively representing 0.02 % of the total). This analysis identifies a possible gap in global funding for vaccine development against these pathogens. However, data captured in the two datasets do not provide the complete global funding picture for the WHO priority AMR pathogens. G-FINDER omits funding for pathogens that are also significant for HICs, many of which are in the WHO's critical priority pathogen category, and the Global AMR R&D Hub does not track industry funding, which may significantly contribute to research on these pathogens. These differences in data captured and the lack of comprehensive data limit the ability to assess the overall global investment in vaccine R&D for WHO's critical priority pathogens.

This study combines the publicly available data on human bacterial vaccine R&D funding, but the limitations of the data preclude a full assessment of the landscape. In addition to the challenges relating to recording final recipients of vaccine investments and financing for the WHO priority pathogens, the databases cover publicly disclosed funding, potentially omitting private investments, confidential agreements, or undisclosed funding details. This underscores the need for improved data collection and reporting mechanisms to capture all relevant funding and research activities. Furthermore, both databases primarily capture vaccine-related projects in infectious disease and AMR R&D, with significantly less data registered for behavioural, policy, intervention, and implementation research. This omission limits understanding the full impact and reach of vaccine research in the context of AMR.

5. Conclusion

Between 2007 and 2024, the global north received most human bacterial vaccine funding, while the global south received less than 20 % of the total funding. This reflects a significant imbalance in investment, with a geographic misalignment between the distribution of funding and the burden of AMR. However, current data tracking lacks information regarding final funding recipients. This, coupled with low domestic investment in LMICs, complicates efforts to understand and address these inequities fully. Most funding was directed towards *M. tuberculosis* and *S. pneumoniae,* with critical gaps in R&D funding data for the WHO AMR critical priority pathogens. Philanthropic funders and intermediary organisations, particularly PDPs, were principal players in mobilising and coordinating resources for bacterial vaccine research in LMICs. The role of PDPs and intermediary funders will remain pivotal in achieving sustainable progress and ensuring vaccine funding is distributed equitably, reflecting the needs of underserved regions. Transparent tracking, reporting, and allocation of funding towards vaccine R&D are crucial to effectively tackling AMR and addressing global health challenges.

CRediT authorship contribution statement

Catherine Fleck-Vidal: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Anna Doubell:** Writing – review & editing, Validation, Formal analysis, Data curation. **Christiane Gerke:** Methodology, Conceptualization. **Usha Lamichhane:** Writing – review & editing, Validation, Data curation. **Lesley Ogilvie:** Writing – review & editing, Validation, Funding acquisition, Data curation. **Ralf Sudbrak:** Writing – review & editing, Resources, Data curation. **Jerome H. Kim:** Writing – review & editing, Funding acquisition. **T. Anh Wartel:** Writing – review & editing, Funding acquisition. **Laura Plant:** Writing – review & editing, Supervision, Resources, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2025.126771.

Data availability

Data will be made available on request.

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