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Breaking barriers: Scientific contributions in virology from women in low- and middle-income countries

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The advancement of science has been a collective effort and benefits from a diversity of views and gender representation. However, support for and recognition of women in science is often insufficient. Despite historically being marginalized by the scientific community, research by women has advanced the field of virology, from the discovery of rotavirus and isolation of human immunodeficiency virus (HIV) to a vaccine for polio and the initial description of a virus' ability to cause cancer. Although women in science, technology, engineering, and mathematics (STEM) fields are continuing to share their diverse wealth of knowledge and innovation, even today many are under-recognized and under-supported in low- and middle-income countries (LMICs). This review will highlight women in virology from LMICs in Africa, Asia, and Latin America where the barriers to scientific education and achievement for women can be far greater than in high income countries. Despite these barriers, the women we profile below have made important contributions to translational virology. We hope this review will contribute to the global expansion of efforts to provide improved access to and retention in scientific careers for women.

KEYWORDS

translational virology, women in STEM, low- and middle-income countries, scientific careers, diversity

Introduction

Women in low- and middle-income countries (LMICs) continue to be significantly under-represented in the biological sciences. For example, women represent only 30% of scientists in sub-Saharan Africa, 23% in Southeast Asia, 17% in South Asia and 44% in Latin America (1). The reasons for this are manifold including traditional gender roles and responsibilities which may serve as barriers for girls and women pursuing education. Discrimination in the workplace and in educational institutions as well as negative stereotypes of the ability of girls and women to excel in scientific pursuits also contribute to the low representation of women in the scientific workforce. The consequences of these barriers are far reaching and impact the scientific questions that are addressed through research, the representation of women in clinical studies, and the lack of same gender mentorship for young women interested in careers in science (2–6). At a time when the world faces important challenges such as climate change, emerging infectious diseases, and numerous health crises the need for scientific innovation and a diversity of approaches is more important than ever. Recent years have also highlighted the importance of skillful scientific communication and how trust in science depends not only on the message, but also the messenger – with demographic features of that messenger influencing their credibility (7). Harnessing the under-utilized potential of girls and women will help bolster the scientific work force and benefit the overall scientific field with fresh insight and an injection of talent and ingenuity.

Following in the footsteps of female virologists recognized for field-changing discoveries (8–12), the scientists we have selected to profile below have addressed important research questions in virology. These range from basic - elucidation of the mechanism of rotavirus entry – to applied - epidemiology and surveillance of emerging viruses - virology. Their research has encompassed viruses transmitted through the fecal-oral route, respiratory droplets, arthropod vectors, blood, and vertically from mother to child. Viral diagnostics and vaccine strategies have also been investigated by this group of accomplished investigators. In sum, the six scientists we profile have collectively studied over fifteen viruses that have the capacity to impact human health. We hope that by highlighting the work of these leading female scientists in LMICs we can focus attention on the urgent need for improved retention and expansion of the female scientific community.

Scientist profiles

Wanda Markotter, PhD

Based at the Centre for Viral Zoonoses, University of Pretoria, South Africa, Professor Markotter is a South African virologist passionate about understanding bat species zoonoses with an interdisciplinary approach. Dr. Markotter's interest in virology stemmed from her fascination with the characteristics of a virus; invisible to the naked eye but causing visible damage to a vulnerable host hence creating avenues for exploring mode of action, prevention, and treatment (13). Dr. Markotter earned her PhD at the University of Pretoria and has since continued her career there. Her current work is focused on investigating and surveilling the impact of African bat species' on host and ecology in the environment while working to develop effective diagnostic assays for known and novel lyssaviruses, coronaviruses, paramyxoviruses, filoviruses, or selected bacterial pathogens (14, 15). The relevance of this work is interdisciplinary in the sense that studying spill-over between humans and bats requires an understanding the biology of both host and vectors of different species. Dr. Markotter and colleagues discovered that the mobility of bat host species' determined coronavirus diversity better than did geographic location and thus also influenced the potential for host-switching/spill-over (16). The COVID-19 pandemic has raised the public awareness on coronaviruses and other zoonoses involving bats. Dr. Markotter is among virologists who studied coronaviruses even before the COVID-19 pandemic, with one example being the detection of betacoronavirus RNA in a subset of Rwandan bats belonging to *Rhinolophus clivosus* (17). Dr. Markotter's findings may be helpful to better understand the potential timing and mechanism of zoonotic virus spread and in preventing or minimizing the effects of coronaviruses once transmission to humans occurs. The leadership roles Dr. Markotter has undertaken have been valuable tools for making her research vision a reality. According to "Future Africa", a pan-African focused research institute, Dr. Markotter serves as a Research Chair leading a project entitled *One Health for Change* under the umbrella of UNICEF Future Africa and has been Principal Investigator for several internationally recognized research grants (18). The vision she has for a sustainable healthier future through an interdisciplinary approach has inspired many students and trainees from South Africa and beyond.

Georgina Njideka Odaibo, PhD

Dr. Odaibo is a Nigerian virologist and Professor of Virology at the University College Hospital (UCH) in Ibadan, Nigeria. She earned her PhD in Virology in 1999 at the University of Ibadan (19). Dr. Odaibo's research in virology incorporates viral epidemiology, diagnostic virology, retrovirology and hepatitis viruses (20). On June 27th 2019, Dr. Odaibo became the first female lecturer from the Department of Virology at the University of Ibadan to give an inaugural speech for the university's lecture series. In her remarks, Dr. Odaibo shared the history of her department and its impact on the field of

virology, as well as her contributions to virology research and, specifically, viral pathogenesis (19). These contributions include understanding HIV spread through sero-epidemiology of HIV infection in Nigeria (21, 22), incidence and severity of respiratory viruses such as respiratory syncytial virus (RSV) in the rural and urban population (23), rotavirus' various genotypes and high infection rate in children (24), and Hepatitis B (HBV) and Hepatitis C (HCV) infections in both patients and healthcare workers in Nigerian hospitals (25), Dr. Odaibo has also pursued quality improvement research and notes the importance of laboratory infrastructure and mentorship for high-quality research. In some of her most cited work, Dr. Odaibo and colleagues described the prevalence of HBV and HCV co-infection in a cohort of people living with HIV in Nigeria. The study revealed 11.9% prevalence of HIV and HBV co-infection supporting World Health Organization (WHO) reports of an overall highest global disease burden of HBV in people with HIV, compared to HCV (26, 27). Dr. Odaibo has been mentored many scientists in training and served in a leadership role as the laboratory coordinator for the US government Harvard PEPFAR project at UCH (20). Dr. Odaibo's strong history of collaboration and team science approach has contributed to her impact nationally and internationally.

Judith Ndongo Torimiro, PhD

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Professor Torimiro, a member of the Cameroon Academy of Sciences, currently serves as Chair of the Department of Biochemistry of the Faculty of Medicine and Biomedical Sciences, concurrently as Coordinator of the Postgraduate School for Health and Environmental Sciences, of the University of Yaoundé I. Professor Torimiro has extensively studied medical biochemistry and applied molecular biology with the goal of using her research to directly address sexually transmitted viral infection-related health challenges in LMICs (28). Dr. Torimiro earned her Ph.D. in Infectious Diseases from the London School of Hygiene and Tropical Medicine (LSHTM) in the United Kingdom (29). In 2008, Professor Torimiro facilitated setting up the United States Centers for Disease Control and Prevention-sponsored program to improve quality control tools for HIV diagnosis in Cameroon (29). She attributes her interest in studying viruses to a drive to answer the question of how viruses (HIV, hepatitis B, hepatitis C and hepatitis delta viruses) are transmitted from a non-human primate to humans as well as from a pregnant woman to the fetus resulting in different outcomes clinically (28). Moreover, Professor Torimiro has conducted extensive research on cross-species transmission of viruses. With colleagues, she identified rare variants of HIV-1, due to high rates of retrovirus cross-species transmission and mutations in the CCR5 HIV co-receptor, in a rural Cameroonian population (30). In the attempt to better understand viral zoonoses, Professor Torimiro was part of a group of collaborators that described a pattern of cross-species transmission of simian T-lymphotropic virus (STLV) and simian foamy virus (SFV) from non-human primates to humans (31, 32). This transmission is thought to occur through behaviors such as bushmeat hunting and consumption of infected non-human primates in rural areas which can eventually spread into urban populations, such as occurred with HIV (31). Moreover, this group discovered the previously unreported HTLV-3 and HTLV-4 among the hunting population in Cameroon (31).

Professor Torimiro holds a collection of awards and leading roles that attest to her work in building the infrastructure for and conducting high quality research within Cameroon. In 2019, while serving as the Director of Laboratories at the "Chantal Biya International Reference Centre for AIDS Research (CIRCB)" in Yaoundé, the World Health Organization (WHO) awarded her the "Sasakawa Health Prize" in recognition of her outstanding work in promoting research on HIV, HBV, and HCV as well as the construction of prominent research institutions in Cameroon (since 1995) (33). She later received a letter of congratulations from the President of the Republic of Cameroon upon this recognition. Professor Torimiro is also passionate about maternal and child health, promoting interventions to prevent mother-to child transmission of HIV, HBV and HCV, and leading the mother infant cohort hepatitis B (MICHepB) Network of four countries in Africa: Zimbabwe, Gabon, Chad and Cameroon. Stemming from this passion, and after completion of her Master's Degree, Professor Torimiro was presented the "Women's Health" Award by the Commonwealth in 1999 for studies she led that reported high prevalence of sexually transmitted infections such as, syphilis, chlamydia, gonorrhea and HIV among pregnant women (28). The results of this work were useful in setting- and scaling-up a program led the Ministry of Public Health in Cameroon to investigate HIV

vertical transmission. She has contributed to the creation of sensitization and screening platforms for women in rural areas in addressing cervical cancer as well as sexually transmitted viral infections. Professor Torimiro has led several international capacity-building workshops geared towards strengthening prevention interventions to mitigate hepatitis B and co-infections (34). Finally, Professor Torimiro is known for her work to empower Cameroonian women through training and mentorship opportunities in health research.

Gagandeep Kang, PhD

Dr. Kang is an Indian virologist and microbiologist. Her academic titles include Professor of Microbiology at Christian Medical College's Division of Gastrointestinal Sciences in Vellore, and Executive Director of the Translational Health Science and Technology Institute (THSTI) in Faridabad, India. Dr. Kang pursued her education at Christian Medical College, earning the following degrees: M.B.B.S. in 1986, M.D. in 1991 and Ph.D. in 1997 (35). Dr. Kang was interested in physics, medicine and history at an early age, then while pursuing graduate level education as well as a post-doctoral fellowship, she was driven to understand the link between rotavirus infection in Indian children and public health (36). Later, as her research on rotavirus expanded, Dr. Kang was involved in the development of ROTAVAC oral vaccine (36). Dr. Kang and colleagues emphasized the importance of rotavirus surveillance, in the face of point mutations and genetic reassortment, using highly sensitive molecular techniques for characterization of viral proteins before implementing new vaccines (37). Alongside her research efforts on rotavirus, owing to her interest in enteric infections and gastrointestinal diseases, Dr. Kang has reported on other diarrheal causing pathogens. In determining the prevalence of intestinal parasites in Southern Indians, Dr. Kang concluded that *Giardia, Cryptosporidium* and Hookworm were the most common in asymptomatic adults, with replication capability and disease burden at least partially determined by host factors (38). Among her numerous accolades, in 2016 the Infosys Prize in Life Sciences was conferred on Dr. Kang in recognition of her work in understanding rotavirus infections and immunity in the Indian population (35). In 2019, Dr. Kang became the first Indian woman to be elected a Fellow in the Royal Society, a renowned scientific academy in the United Kingdom, for her inter-disciplinary research investigating enteric infections affecting children in India, her work building national rotavirus and typhoid surveillance networks and facilitating vaccine trials, as well as providing clinical translational medicine training opportunities for students and faculty (39, 40).

Meng Ling Moi, PhD

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Currently a Professor of Developmental Medical Sciences at the Graduate School of Medicine, University of Tokyo, Dr. Moi is an accomplished Malaysian virologist (41). Dr. Moi earned her Ph.D. in medical science from Tsukuba University, Japan. Although her graduate education and academic career have been based in Japan, Dr. Moi has focused her research on virologic diseases that greatly impact countries in Southeast Asia, including her home. In fact, her interest in dengue virus (DENV) stems from personal experience as she and her family suffered from dengue infections, coupled with the lack of information about the disease in Malaysia at the time she initiated her studies (42). Dr. Moi and colleagues investigated antibody-dependent enhancement (ADE) *in vitro* during DENV infection and revealed a mechanism by which ADE development may worsen infection and clinical disease (43). In line with her interest in mosquito-borne infections, Dr. Moi also conducts studies of Zika virus (ZIKV). Between 2013 and 2014, before the 2015 re-emergence in Brazil, French Polynesia experienced the largest ZIKV outbreak worldwide (44). Dr. Moi and colleagues analyzed imported cases of ZIKV in Japan that originated from the French Polynesia outbreak. The results first showed that ZIKV particles can be detected in urine and an association with thrombocytopenia and leukopenia in infected individuals, similar to that caused by DENV and yellow fever virus (45). Dr. Moi and colleagues also emphasized the importance of surveillance for ZIKV in Southeast Asia. Dr. Moi's work to control infectious diseases through epidemiological and phylogenetic analysis of mosquito-borne viruses, and evaluation of vaccine safety and effectiveness using an antibody test she developed for dengue fever vaccines, led to the Japan Agency for Medical Research and Development (AMED) Award being bestowed on her in 2020. She was the first foreign researcher to be granted this prestigious award (46). Dr. Moi has also received the Japanese Society of Virology Sugiura Award in 2018 (47), the Japanese Society of Tropical Medicine Female Researcher Prize in 2019, the Mirai-ni-Habataku Female Researcher Award from Nagasaki University in 2018 (48) and the Best Paper Award from the Institute of Tropical Medicine at Nagasaki University in 2017 for the paper titled "Zika virus infection and microencephaly in Vietnam".

Susana López Charretón, PhD

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Mexican by nationality, Dr. López Charretón is a virologist based at National Autonomous University of Mexico (UNAM), where she earned her PhD in 1986. From a young age Dr. López Charretón had an interest in general biology and chemistry that led to biomedical research and eventually pursuing a career researching rotavirus starting in the '80s when the epidemiology of the virus was unknown in Mexico (49). Dr. López Charretón has conducted pioneering discoveries of rotavirus entry, describing rotavirus' spread from the mouth and skin to infection and replication in the small intestine (50). Unraveling the mechanisms of rotavirus entry and replication was a groundbreaking discovery to understand rotavirus infection. In a review, *Multistep entry of rotavirus into cells: a Versaillesque dance*, Dr. López Charretón and colleagues beautifully outlined the steps of rotavirus entry as an event dependent on multiple rotavirus virus-cell receptor interactions resulting in an organized viral protein conformational change, raft-dependent endocytosis, and specific virus tropism towards mature small intestine villi enterocytes (51). More recently, Dr. López Charretón and her team described how rotaviruses fight back against the antiviral responses of the cell (52). Dr. López Charretón was a Howard Hughes International Research Fellow two consecutive times from 2000-2010 and served as a permanent member of the NIH review panel VIRA study section from 2010-2016. She has been an Editor of the Journal of Virology since 2013. Dr. López Charretón has won numerous awards for her research. In recognition of her work in understanding rotavirus virology, epidemiology, pathogenesis, immune responses, and in developing new diagnostic tests, the United Nations Educational, Scientific and Cultural Organization (UNESCO) awarded Dr. López Charretón the L'Oreal-UNESCO Award for Women in Science in 2012. This award is given annually to one woman per region and Dr. López Charretón was selected for Latin America (53, 54). In 2013 Dr. López Charretón was awarded the UNAM Prize in Natural Sciences, and in 2018 the Jesuit University System bestowed her with an honorary doctorate (55). Dr. López Charretón is very interested in science outreach, particularly for children. Since 2018, with the support of the Mexican Society for Virology, she has co-authored four books for children with the goal of explaining how vaccines work, and why it is important to get vaccinated (56). The books, available online free of charge, have been translated by virologists into at least fifteen languages. In March 2021, Dr. López Charretón was elected as a member of El Colegio Nacional, a Mexican public institution committed to the public communication of science, technology, and humanistic culture (57, 58).

Summary

The important themes that emerged in profiling these accomplished female scientists include their choice of research foci, their contributions to building research infrastructure and programs in their home countries, and their dedication to mentoring. Many of these scientists have focused their research in areas of virology that specifically impact the health of women and children, and all have made systematic efforts to mentor female scientists in training. We hope this article serves to highlight these researchers as role models for young girls and women globally and to help broaden the visibility of women in virology from LMICs who too often are unsung heroines of important scientific work.

Ethics statement

Written informed consent was obtained from Drs. Torimiro, Moi, and López Charretón for the publication of any potentially identifiable images or data included in this article.

Author contributions

TC conducted research and interviews. All authors contributed to writing the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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