

Essential standards for perinatal care of women and children living in prison



Marie Claire Van Hout, Alexa Johnson-Gomez, Reda Madroumi, Ivan Calder, Barbara Frey, Julie Matonich



The female prison population continues to rise, with prisons worldwide failing to meet international human rights standards. Many are overcrowded, poorly resourced, and unsafe, especially for women. Women in prison are an obstetric group at high risk, with deficits in perinatal care leading to preventable maternal and child morbidity and mortality. Mother–child imprisonment and mother–child separation can have substantial intergenerational health and social consequences. In this Viewpoint, we present essential standards for perinatal care of women and children who are incarcerated, aligned to human rights obligations, prioritising alternatives to imprisonment, and where custodial sentences are applied, emphasising essential core best practices in prison (inclusion of prisons in national maternal health strategies, resourcing of prison facilities, services, staffing, and medical competencies, comprehensive medical management of pregnancy, obstetric and postpartum care, and release planning). To ensure the rights of women and children in diverse contexts are upheld, standards should be enforced through independent inspections, clinical audits, and integrated public and prison health monitoring of perinatal health outcomes.

The global prison population has remained steady, at 11·5 million in 2025.¹ However, the proportion of women who are incarcerated is continuing to rise at an alarming rate.^{1,2} More than 733 000 women and girls are incarcerated worldwide, with the female prison population increasing by 57% since 2000.^{1,2} Steep increases are observed in South America (Brazil), Central America (El Salvador and Guatemala), and southeast Asia (Cambodia and Indonesia). The USA has the highest number of women living in prison (approximately 174 607) in the world.² Incarceration rates of women are generally underpinned by punitive responses to drug-related offences, offences directly or indirectly related to gender-based violence, and non-violent, low-grade offences, often linked to poverty.^{1–3} Women who are incarcerated often have complex and substantial health needs, including psychiatric illness, substance dependence, and trauma,^{1,4} and might experience pregnancy and motherhood in prison.^{5–7}

Global estimates of numbers of children or pregnancies in prisons are unavailable as many countries do not collect robust data.⁸ The most recent UN figures estimate that 19 000 children live with their primary caregiver in prison, almost all with their mothers.⁹ There is no common approach to the management and care of pregnant women, breastfeeding women, and infants when deprived of their liberty, or quality standards to deal with maternal and paediatric health needs,^{10–12} nor is judicial decision making generally focused on the “best interests of the child” as required by the UN Convention on the Rights of the Child.^{13,14} The degree to which alternatives to imprisonment are supported in legislation, used, and resourced varies worldwide.^{12,15–17} When custodial sentences are imposed, as is the case for more serious offences, prison system policies include separation of mother and child on entry to prison, housing of mother and child within the mainstream prison population or in separate cells, or placement in mother and baby units.^{8,14} Countries have different

specifications regarding the duration of time that children can remain with their mother in prison, with most countries imposing a maximum age (generally when breastfeeding ends).^{8,17,18}

Despite recognised international human rights norms and obligations regarding the treatment of all people who are incarcerated (eg, UN Standard Minimum Rules for the Treatment of Prisoners¹⁹ and UN Rules for the Treatment of Women Prisoners and Non-Custodial Measures for Women Offenders²⁰), many prisons worldwide fail to meet such standards and are overcrowded, poorly resourced, and unsafe, especially for women.^{1,21,22} National Preventive Mechanisms under the Optional Protocol to the Convention Against Torture and other Cruel, Inhuman and Degrading Treatment or Punishment (OP-CAT)²³ and UN treaty body committees routinely document neglect and rights violations concerning the situation and treatment of pregnant women and mothers worldwide who are incarcerated.^{14,22,24}

Women who enter prison during pregnancy frequently experience long-standing social and structural inequities that pre-date their incarceration, including poverty, gender-based violence, trauma, unstable housing, poor access to antenatal care, and disproportionately high rates of substance use and mental health conditions.^{1–4,10} These intersecting determinants mean that worse perinatal outcomes among women in prison cannot be attributed solely to the prison environment. Imprisonment often functions as a form of so-called compensatory care, in which services delivered in custody attempt to fill gaps arising from broader systemic inequities and poor access to care in the community.^{3,4,6,7,10} Pregnancy in prison is clinically high risk, with deficits in perinatal care leading to a host of preventable maternal and paediatric morbidity and mortality outcomes.^{5–7,10,24–26} Risks are amplified due to failure of prison authorities to ensure safe environments, evidence of cruel, degrading, and inhuman treatment (eg, solitary confinement, use of restraints during childbirth), inaccessibility of emergency

Lancet Public Health 2026;
11: e197–201

Published Online
January 14, 2026
[https://doi.org/10.1016/S2468-2667\(25\)00320-2](https://doi.org/10.1016/S2468-2667(25)00320-2)

Office of the Vice President of Research, Innovation and Impact, South East Technological University, Waterford, Ireland (Prof M C Van Hout PhD); Children of Incarcerated Caregivers (and the Global Prison Nursery Network), Minneapolis, MN, USA (A Johnson-Gomez JD, J Matonich JD); School of Psychology, Liverpool John Moores University, Liverpool, UK (R Madroumi MSc); Health through Walls, Miami, FL, USA (I Calder MSc); Human Rights Program, University of Minnesota, Minneapolis, MN, USA (B Frey JD)

Correspondence to:
Prof Marie Claire Van Hout, Office of the Vice President of Research, Innovation and Impact, South East Technological University, Waterford X91 K0EK, Ireland

MarieClaire.VanHout@setu.ie

obstetrics, and insufficient access to quality sexual, reproductive and paediatric health care.^{5-7,10-12,22,25,26} Mother-child imprisonment or separation can cause further substantial, lifelong, and intergenerational health and social consequences.^{5-7,10}

Recognising these underlying drivers of disadvantage is essential to understanding the heightened vulnerability of pregnant women in detention and the need for comprehensive, rights-aligned reforms. There is growing international consensus that imprisonment of pregnant and postpartum women is rarely justified and is inconsistent with human rights obligations and the requirement to prioritise the best interests of the child.^{11-15,17,18} Decongestion measures, including through greater application and prioritisation of alternatives to imprisonment, and immediate, evidence-informed reforms to respect, protect, and fulfil maternal and paediatric health rights and outcomes in prisons are crucial.^{3,4,7,11-13,15,17,18,24,27-29} Evidence regarding community-based alternatives remains scarce, yet what is available highlights their potential to reduce harms and strengthen continuity of perinatal care.^{12,14-17} Combined with identified risks associated with perinatal care in prison, including preventable maternal and neonatal morbidity and mortality, lack of emergency obstetric access, unsafe conditions, and trauma-exacerbated environments, these factors support the argument that non-custodial measures should be the presumptive response, with deprivation of liberty used only when no safe alternative exists.

In this Viewpoint, we present a series of essential standards for perinatal care and management of pregnant and or breastfeeding women and their infants when in contact with the criminal legal system, aligned to international human rights obligations. The standards are equally applicable to other settings in which women are deprived of their liberty, such as immigration detention facilities. The panel presents the 42 standards spanning seven dimensions, which were developed by a multidisciplinary coauthor team (medicine, public health, law, and psychology experts) based on a rapid narrative review²⁷ and refined with consensus agreement by a global expert panel (appendix pp 1-13). 36 professionals (including with lived experience) representing policy makers, prison health, clinical, and social care providers, lawyers, civil society, and researchers from Europe, North America, Asia, and sub-Saharan Africa (27 females, 9 males) agreed on the standards (appendix p 2).

By emphasising equivalency of health outcomes rather than equivalency of services, the standards acknowledge global variation in maternal health systems and the need for context-specific implementation strategies across diverse jurisdictions. They are intended to not only improve perinatal care for women who are incarcerated and their children but to shift practice towards community-based, trauma-informed, and rights-grounded models of

support. By meeting the broad-based human rights obligations as provided in the UN Standard Minimum Rules for the Treatment of Prisoners and the UN Rules for the Treatment of Women Prisoners and Non-Custodial Measures for Women Offenders,^{19,20} the standards are a first step to supporting continued efforts to reduce prison overcrowding and to encourage greater application of alternatives to imprisonment of women during the perinatal period. We recommend the further development of UN technical guidance and the translation of these standards into government policies specifically directed at this vulnerable cohort.

By encouraging equivalency of maternal and paediatric outcomes, in addition to care that is at least equivalent to that available in the community, and implementing integrated health care spanning community and prison, maternal and child health can be better protected and ensured. Greater investment in community health care, integration of lived experience, and monitoring of perinatal outcomes through independent oversight mechanisms are essential to reducing preventable morbidity and mortality among mothers and infants affected by the criminal legal system. Clinical audits and independent inspection mechanisms including those created by OP-CAT are crucial to monitoring prison standards and ensuring access to and quality of provided health care. Monitoring efforts help to ensure compliance with human rights and accountability and play an important part in supporting and ensuring positive perinatal health outcomes for mothers and children living in prison.^{14,22,24,28,29}

In this context, the work of non-governmental organisations (NGOs) in helping to implement the essential minimum standards of perinatal care for women and their children living in prison systems is of particular importance. For example, the international NGO Health through Walls operates globally to strengthen health care in prisons, by partnering with correctional systems in low-income countries to improve continuity of care, including access to medicines and diagnostic equipment, capacity building for support staff, and developing sustainable prison health systems. Their model integrates public, maternal, and paediatric health approaches with human rights obligations by working to address many of the gaps in implementation of such essential minimum standards of perinatal care and management in prisons.

Regardless of community level of perinatal care and prison context (high or low resource settings), very little is known regarding the perinatal and longitudinal health outcomes of mothers and children in contact with the criminal legal system pertaining to psychosocial, health, criminal, legal, and mortality outcomes of women (and their children) who experience alternatives to imprisonment, and of those who experience the perinatal period in prison. Further research is warranted regarding due process in vulnerability assessment and judicial

For more on Health through Walls see <https://healththroughwalls.com/>

See Online for appendix

Panel: Essential standards for perinatal care of women and their children living in prison

Prioritisation of alternatives to imprisonment

- 1 Alternatives to imprisonment during the perinatal period should be considered on a case-by-case basis and be prioritised by the criminal legal system, where possible, to ensure the safety of the mother and the child
- 2 Women who are expected to give birth within the term of their imprisonment should remain in the community (if possible), in an environment where shelter, food, perinatal care, and substance use disorder treatment are readily available
- 3 During the perinatal period, alternatives to imprisonment such as community-based non-custodial measures should, at a minimum, include options for house arrest and group homes
- 4 Community-based non-custodial measures during the perinatal period should be funded at a level to provide support for perinatal and postnatal care that is equivalent to the community standard

Core principles of perinatal care in prison

- 5 Women in prison should be provided with gender-specific, culturally appropriate, trauma-informed health-care services that meet or exceed the standards of care available in the community
- 6 A balance should be maintained between implementing necessary security measures in prison and the provision of equitable support for health, wellbeing, and assistance
- 7 Perinatal care programmes in prisons should be based on a national strategy for perinatal care in the community and equivalent to that level of care
- 8 Adequate and equitably distributed resources, including finance, equipment, staffing, and training, should be allocated to clinical and support services across the perinatal period in prison to ensure long-term sustainability and accessibility for these services
- 9 Clear articulation of medical and support services, roles, and responsibilities and the relevant timeframes should be defined and shared on admission into prison and displayed at places accessible for the female prison population
- 10 Perinatal care programmes in prison should offer evidence-based pre-pregnancy and postpartum care, regular medical assessment, care for health and wellbeing, and support in an integrated multiagency (public, private, non-governmental) partnership approach designed to uphold the rights of women who are incarcerated (including those pregnant, breastfeeding, or with children) to equivalence of health care and the best interests of the child
- 11 Perinatal care programmes in prison should be provided by trained staff and with necessary infrastructure
- 12 All pregnant women and women in the postpartum period should be offered confidential mental health screening and have access to appropriate and ongoing counselling and psychosocial support

- 13 Addiction treatment should be available whenever clinically indicated across the perinatal period, accounting for previous victimisation, the special needs of pregnant women and babies who might be born with neonatal abstinence syndrome, and women with children

Management of pregnancy in prison

- 14 Women living in prison should have timely access to pregnancy testing, especially on admission, and timely access to the results
- 15 Pregnant women in prison should have timely access to pregnancy counselling, including information on abortion, prenatal and postnatal care, delivery expectations, developing a pregnancy plan, and infant placement options as per the country-specific laws
- 16 Beyond receiving information, pregnant women in prison should have the opportunity to ask questions, change their minds about their decisions, and have timely access to the services or options they choose to pursue
- 17 Pregnant women in prison should be offered timely and comprehensive health assessments, including screening for conditions such as HIV, hepatitis C, or any congenital anomalies, with access to timely treatment and care that is responsive to their specific needs, including the prevention of mother-to-child transmission
- 18 Substance use during pregnancy should not be criminalised, to allow for pregnant women living in prison to be screened and treated for substance use without fear of additional punishment, stigma, and legal repercussions
- 19 Core components of prenatal care in prison should include:
 - Medical examinations carried out by health-care professionals, as equivalent to the community
 - Access to diagnostic tests in accordance with national guidelines
 - Appropriate referral pathways to relevant community and external services to ensure continuity of care with suitable transport options
 - Viral screening and administration of recommended vaccines in accordance with national guidelines
 - Provision of trauma-informed, culturally appropriate, and gender-responsive care, including substance use disorder treatment and pregnancy loss care when needed
 - Prenatal education and access to nutritional supplementation, including prenatal vitamins
 - Development of an individualised birth and postpartum care plan, including breastfeeding and mother–infant contact where appropriate
 - A focus on intersectionality when providing individualised care to individuals who are incarcerated
- 20 Pregnant women living in prison should receive nutrition needed to support a healthy pregnancy

(Continues on next page)

(Panel continued from previous page)

- 21 Employment and recreation in prison should be available, providing pregnant women with a healthy balance of rest, activity, exercise, and social participation
- 22 Pregnant women living in prison should not be placed in solitary confinement under any circumstances

Obstetric care, complications, and labour during imprisonment

- 23 Pregnant women in prison should have access to unscheduled or emergency obstetric visits on a 24 h basis
- 24 All correctional and clinical personnel should be trained to recognise and respond appropriately and seriously to any signs or symptoms suggestive of pregnancy-related complications, ensuring timely referral and intervention
- 25 Pregnant women living in prison should be transported in a safe and timely manner to a maternity hospital for labour and delivery
- 26 Pregnant women living in prison should receive counselling on their delivery options and be actively involved in the decision-making process wherever possible
- 27 Pregnant women living in prison should be allowed the assistance of a birth supporter of their choice throughout the perinatal period, such as a doula, family member, or friend
- 28 Instruments of restraint should never be used on women who are incarcerated during labour, during childbirth, and immediately after childbirth
- 29 The only exception is when the woman poses an immediate and serious threat of harm to herself or others that is certified by a licensed professional and cannot be reasonably prevented by other means, and must be closely monitored
- 30 If restraint is needed, it should be the least restrictive method possible to ensure safety and must never include restraints that interfere with leg movement or the ability to break a fall

Postpartum care and conditions in prison

- 31 Postpartum medical care should be provided by correctional health professionals and community public health-care providers to ensure continuity of care and adherence to best practice standards
- 32 Women living in prison with their newborns and who choose to breastfeed should receive education and support for breastfeeding according to community standards and the proper equipment to express milk

- 33 Postpartum women living in prison should be offered confidential mental health screening, counselling, and support, especially when parent and infant are separated
- 34 Where infants are permitted to stay in prison, facilities should create healthy and safe environments that allow women living in prison to hold and breastfeed their babies
- 35 Facilities should support family visitation in designated areas that are suitable for young children and new parents
- 36 Infant care in prisons should meet the community standard of paediatric care, including regular examinations by a qualified provider and provision and access to administration of routine vaccinations in accordance with national guidelines
- 37 Women living in prison with infants must not be placed in solitary confinement

Decisions and processes for the separation of mother and child

- 38 Official decisions as to when a child is to be separated from its mother should be based on individual assessments and the best interests of the child within the scope of relevant national laws and options available in the community
- 39 The removal of the child from prison or from the hospital following birth should be always undertaken with sensitivity, even when suitable alternative care arrangements, in keeping with the best interest of the child, have been identified and, in the case of foreign-nationals living in prison, made in consultation with consular officials
- 40 After children are separated from their mothers and placed with family or relatives or in other alternative care, women who are incarcerated should be given the maximum possible opportunity to meet with their infants or children in addition to usual visitation, provided it is in the best interests of the children and when public safety is not compromised

Planning for release

- 41 When planning for release, a continuation of supportive financial, mental health, and parenting resources, including referrals to community services, should be accessible and offered to women and their families to facilitate successful reintegration
- 42 Integrated case management, including continuity of medical care, should be actively supported on release to the community to nurture and stabilise parent-child relationships

decision making and economic feasibility or cost models for implementing the 42 standards. Additional areas of research focus include the complex health needs of women living in prison, socioeconomic and contextual differences in quality of community and prison perinatal care and health-care governance, and sociopolitical understanding regarding political resistance or ideological barriers to reform. Participatory research—co-designed with people with lived experience of pregnancy and parenthood in

prison—which illustrates the voices of women in prison must play a central part in supporting continued advocacy for alternatives to imprisonment, improved prison standards, and support of families affected.

Contributors

MCVH conceived the Viewpoint and was responsible for development, drafting, and final submission. BF, JM, IC, AJ-G, and RM provided medical, prison system, health psychology, and human rights law expertise in drafting and review of the Viewpoint before submission.

All authors contributed to drafting and revising the manuscript and approved the final version.

Declaration of interests

We declare no competing interests.

Acknowledgments

The authors wish to acknowledge the contribution of the expert panel members of the International Corrections and Prisons Association Healthcare in Prisons Network and the Children of Incarcerated Caregivers Global Prison Nursery Network in developing and agreeing on the 42 standards.

References

- 1 Penal Reform International. Global prison trends 2025. May, 2025. www.penalreform.org/resource/global-prison-trends-2025/ (accessed Sept 22, 2025).
- 2 Fair H, Walmsley R. World female imprisonment list sixth edition. Women and girls in penal institutions, including pre-trial detainees/remand prisoners. Institute for Crime & Justice Policy Research. 2025. www.prisonstudies.org/sites/default/files/resources/downloads/world_female_imprisonment_list_6th_edition.pdf (accessed Sept 22, 2025).
- 3 Penal Reform International, Women Beyond Walls. From poverty to punishment. Examining laws and practices which criminalise women due to poverty or status worldwide. March, 2025. www.womenbeyondwalls.org/_files/ugd/2d77c8_728255cde77e498189391b05638667ae.pdf (accessed Sept 22, 2025).
- 4 van den Bergh BJ, Gatherer A, Fraser A, Moller L. Imprisonment and women's health: concerns about gender sensitivity, human rights and public health. *Bull World Health Organ* 2011; **89**: 689–94.
- 5 Kirubarajan A, Tsang J, Dong S, et al. Pregnancy and childbirth during incarceration: a qualitative systematic review of lived experiences. *BJOG* 2022; **129**: 1460–72.
- 6 Bard E, Knight M, Plugge E. Perinatal health care services for imprisoned pregnant women and associated outcomes: a systematic review. *BMC Pregnancy Childbirth* 2016; **16**: 285.
- 7 Hawkins SS. Reproductive health care for incarcerated women in the prenatal and postpartum periods. *J Obstet Gynecol Neonatal Nurs* 2024; **53**: 220–33.
- 8 Van Hout MC, Klankwarth UB, Fleißner S, Stöver H. Children living in prison with a primary caregiver: a global mapping of age restrictions and duration of stay. *Lancet Child Adolesc Health* 2023; **7**: 809–14.
- 9 UN General Assembly. Global study on children deprived of liberty. July 11, 2019. <https://docs.un.org/en/A/74/136> (accessed Sept 22, 2025).
- 10 Alirezai S, Latifnejad Roudsari R. The needs of incarcerated pregnant women: a systematic review of literature. *Int J Community Based Nurs Midwifery* 2022; **10**: 2–17.
- 11 Inter-American Commission on Human Rights. Women deprived of liberty in the Americas. March 8, 2023. www.oas.org/en/iachr/reports/pdfs/2023/Informe-Mujeres-privadas-libertad_ENG.pdf (accessed Sept 22, 2025).
- 12 Association for the Prevention of Torture. Global report on women in prison analysis from National Preventive Mechanisms. December, 2024. https://www.apt.ch/sites/default/files/2025-06/APT_Women%20in%20Prisons_Global%20Report_EN_FINAL.pdf (accessed Sept 22, 2025).
- 13 Johnson-Gomez A, Matonich J. To prison, with mom: international due process issues for children and mothers posed by prison nurseries. *Columbia J Gend Law* 2025; **46**: 15–34.
- 14 Van Hout MC, Fleißner S, Klankwarth UB, Stöver H. “Children in the prison nursery”: global progress in adopting the Convention on the Rights of the Child in alignment with United Nations minimum standards of care in prisons. *Child Abuse Negl* 2022; **134**: 105829.
- 15 Center for Leadership Education in Maternal & Child Public Health, University of Minnesota-Twin Cities, School of Public Health. Alternatives to incarceration for pregnant & postpartum people in the U.S. national university based collaborative on justice involved women and children (JIWC). 2023. <https://mch.umn.edu/wp-content/uploads/2023/03/JIWC-Policy-Brief-Alternatives-to-Sentencing-3.2023-1.pdf> (accessed Sept 22, 2025).
- 16 Giacomello C, Garcia Castro T. Imprisoned at home: women under house arrest in Latin America. July, 2020. www.wola.org/analysis/women-under-house-arrest-in-latin-america/ (accessed Sept 22, 2025).
- 17 Loucks N. Alice Wambui Macharia, Rights of the child, mothers and sentencing: the case of Kenya. *Punishm Soc* 2024; **26**: 443–45.
- 18 Van Hout MC, Fleißner S, Klankwarth U, Stöver H. Children living with incarcerated mothers are invisible and neglected in the global prison population. *Lancet Child Adolesc Health* 2024; **8**: 317–19.
- 19 UN Office on Drugs and Crime. The United Nations standard minimum rules for the treatment of prisoners (the Nelson Mandela Rules). 2016. https://www.unodc.org/documents/justice-and-prison-reform/Nelson_Mandela_Rules-Ebook.pdf (accessed Sept 22, 2025).
- 20 UN Office on Drugs and Crime. United Nations rules for the treatment of women prisoners and non-custodial measures for women offenders (the Bangkok Rules). March 16, 2011. https://www.unodc.org/documents/justice-and-prison-reform/Bangkok_Rules_ENG_22032015.pdf (accessed Sept 22, 2025).
- 21 United Nations Office on Drugs and Crime. United Nations system common position on incarceration. April, 2021. www.unodc.org/res/justice-and-prison-reform/nelsonmandelarules-GoF/UN_System_Common_Position_on_Incarceration.pdf (accessed Sept 22, 2025).
- 22 Van Hout MC, Fleißner S, Stöver H. # me too: global progress in tackling continued custodial violence against women: the 10-year anniversary of the Bangkok Rules. *Trauma Violence Abuse* 2023; **24**: 515–29.
- 23 UN. Optional protocol to the convention against torture and other cruel, inhuman and degrading treatment or punishment. Dec 18, 2002. <https://www.ohchr.org/en/instruments-mechanisms/instruments/optional-protocol-convention-against-torture-and-other-cruel> (accessed Sept 22, 2025).
- 24 Van Hout MC, Fleißner S, Stöver H. Women's right to health in detention: United Nations Committee observations since the adoption of the United Nations rules for the treatment of women prisoners and non-custodial measures for women offenders ('Bangkok Rules'). *J Hum Rights Pract* 2023; **15**: 138–55.
- 25 Brawley V, Kurnat-Thoma E. Use of shackles on incarcerated pregnant women. *J Obstet Gynecol Neonatal Nurs* 2024; **53**: 79–91.
- 26 Van Hout MC, Mhlanga-Gunda R. Contemporary women prisoners health experiences, unique prison health care needs and health care outcomes in sub Saharan Africa: a scoping review of extant literature. *BMC Int Health Hum Rights* 2018; **18**: 31.
- 27 Van Hout MC, Frey B, Matonich J, et al. Global reform and diverse approaches regarding the care of pregnant and breastfeeding women in contact with the criminal legal system. *Lancet Obstet Gynaecol Womens Health* 2025; **1**: e314–19.
- 28 Knittel A, Sufrin C. Maternal health equity and justice for pregnant women who experience incarceration. *JAMA Netw Open* 2020; **3**: e2013096.
- 29 Usigbe J, Macey E, Klemme P, Williams M, Turman JE Jr. Applying a maternal standards of care audit tool and quality improvement process to improve healthcare for pregnant women in prison. *Int J Offender Ther Comp Criminol* 2023; **69**: 2050–66.

Copyright © 2026 The Author(s). Published by Elsevier Ltd. This is an Open Access article under the CC BY 4.0 license.