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EXPERIENCE OF LONG-TERM OBSERVATION OF AN EXPOSED POPULATION: LESSONS FOR REGIONAL HEALTH MONITORING PROGRAMS

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Abstract

Background. Over two decades of medical observation have been conducted among residents living near the Semipalatinsk Nuclear Test Site, an area affected by chronic exposure to ionizing radiation. This study focuses on thyroid diseases, which are known to be among the most radiosensitive conditions following nuclear fallout.

Materials and Methods. A cohort of 3,240 individuals who underwent thyroid ultrasound examinations between 1998 and 2002 was selected for long-term follow-up. Vital status, clinical diagnoses, and registry data were regularly updated. In 2023–2024, a detailed questionnaire was administered to 1,099 surviving participants to evaluate lifestyle, behavioral, and reproductive risk factors. Individual thyroid radiation doses were retrospectively estimated based on age at exposure, place of residence, and dietary patterns.

Results. The overall prevalence of thyroid disorders reached 63%, with 33% of respondents reporting the use of hormone replacement therapy. The highest rates were observed among individuals with reconstructed thyroid doses in the range of 100–300 mGy. The integration of survey findings with clinical and dosimetric data allowed for a more comprehensive understanding of dose-dependent health effects.

Conclusion. The results confirm the long-term impact of low-to-moderate radiation exposure on thyroid health and support the importance of integrated health monitoring approaches. This experience offers practical lessons for developing regional health surveillance systems in other chronically exposed populations.

Keywords*: radiation exposure, health monitoring, thyroid gland, Semipalatinsk Nuclear Test Site, cohort study.*

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Резюме

ОПЫТ МНОГОЛЕТНЕГО НАБЛЮДЕНИЯ ЗА ПОСТРАДАВШЕЙ ПОПУЛЯЦИЕЙ УРОКИ ДЛЯ РЕГИОНАЛЬНЫХ ПРОГРАММ МОНИТОРИНГА ЗДОРОВЬЯ

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Введение. На протяжении более 20 лет проводился мониторинг состояния здоровья населения, проживающего в районах, прилегающих к Семипалатинскому испытательному полигону. Основное внимание уделено заболеваниям щитовидной железы как органа, особенно чувствительного к радиационному воздействию.

Материалы и методы. В исследование включена когорта из 3240 человек, прошедших ультразвуковое обследование щитовидной железы в 1998–2002 годах. Сбор клинических данных, информации о vital-статусе и результатах диспансерного наблюдения продолжался в течение всего периода. В 2023–2024 гг. было проведено анкетирование 1099 живых участников для оценки поведенческих и репродуктивных факторов. Индивидуальные дозы облучения щитовидной железы были реконструированы с учетом возраста на момент воздействия, места проживания и особенностей питания.

Результаты. У 63% опрошенных ранее диагностированы заболевания щитовидной железы, 33% получали гормональную терапию. Наибольшая распространенность патологии отмечена среди лиц с реконструированной дозой облучения 100–300 мГр. Объединение анкетных, клинических и дозиметрических данных позволило выявить дозозависимые эффекты и поведенческие модификаторы риска.

Заключение. Результаты подтверждают отдаленное влияние хронического радиационного воздействия на эндокринное здоровье и подчеркивают необходимость комплексных региональных программ наблюдения за пострадавшими популяциями.

Ключевые слова: *радиационное воздействие, мониторинг здоровья, щитовидная железа, Семипалатинский испытательный ядерный полигон, когортное исследование.*

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Түйіндеме

РАДИАЦИЯЛЫҚ ӘСЕРГЕ ҰШЫРАҒАН ХАЛЫҚТЫ КӨПЖЫЛДЫҚ БАҚЫЛАУ ТӘЖІРИБЕСІ: ӨҢІРЛІК ДЕНСАУЛЫҚ МОНИТОРИНГІ БАҒДАРЛАМАЛАРЫ ҮШІН САБАҚТАР

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Кіріспе. Семей ядролық сынақ полигонына жақын орналасқан елді мекендерде тұратын халықтың денсаулық жағдайы 20 жылдан астам уақыт бойы жүйелі түрде бақыланып келеді. Бұл зерттеуде радиациялық әсерге аса сезімтал ағзалардың бірі – қалқанша безі ауруларына ерекше назар аударылды.

Материалдар мен әдістер. Зерттеуге 1998–2002 жылдар аралығында қалқанша безінің ультрадыбыстық тексеруінен өткен 3240 адам енгізілді. Мониторинг барысында өмірлік мәртебе, клиникалық диагноздар және медициналық деректер тұрақты түрде жаңартылып отырды. 2023–2024 жылдары 1099 тірі қатысушы арасында сауалнама жүргізіліп, мінез-құлықтық және репродуктивті факторлар бағаланды. Жеке дозалар жас, тұрғылықты жер және тамақтану үлгілерін ескере отырып қайта есептелді.

Нәтижелер. Сауалнамаға қатысқандардың 63%-ында қалқанша безі ауруы анықталған, ал 33%-ы гормоналды терапия алған. Ең жоғары көрсеткіштер 100–300 мГр дозасын алғандар арасында тіркелді. Анкеталық, клиникалық және дозиметриялық деректерді біріктіру арқылы дозалық тәуелділік пен қауіп факторлары арасындағы байланыс айқындалды.

Қорытынды. Созылмалы радиациялық әсердің эндокриндік денсаулыққа ұзақ мерзімді әсері дәлелденді. Бұл зерттеу аймақтық деңгейде тұрақты денсаулық мониторингін дамыту қажеттігін көрсетеді және басқа да зардап шеккен өңірлерге үлгі бола алады.

Түйінді сөздер: *радиациялық әсер, денсаулықты бақылау, қалқанша безі, Семей ядролық сынақ полигоны, когорттық зерттеу.*

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Introduction

The Semipalatinsk Nuclear Test Site (SNTS), located in Eastern Kazakhstan, was the primary testing ground for the Soviet Union's nuclear weapons program from 1949 to 1989. Over 450 nuclear detonations were conducted at the site, including 116 atmospheric tests, resulting in widespread dispersion of radioactive materials. Estimates suggest that hundreds of thousands of residents in the surrounding areas were exposed to both external gamma radiation and internal exposure through inhalation and ingestion of radionuclides [1,5,7].

Unlike acute nuclear accidents, such as Chernobyl or Fukushima, the radiation exposure in the SNTS region occurred under peacetime conditions and often went unrecognized for years. Many communities remained in place during and after testing, receiving prolonged, low-to-moderate doses over time. This scenario created a unique epidemiological situation of chronic exposure, which continues to impact public health across generations [7].

In response to rising concerns about the long-term consequences of nuclear testing, the government of Kazakhstan launched a structured health monitoring initiative in the late 1990s [1,11]. A central focus was the thyroid gland—an organ known for its high radiosensitivity, particularly in individuals exposed during early childhood [2,6,12]. Early studies in the SNTS region and similar contexts (e.g., Belarus, French Polynesia, the Marshall Islands) have demonstrated elevated rates of thyroid nodules, hypothyroidism, and autoimmune conditions decades after exposure [3,6,13].

The cohort analyzed in this study was formed through extensive fieldwork conducted from 1998 to 2002, involving ultrasound screening and demographic data collection across radiation-affected settlements. In 2023–2024, a targeted follow-up was conducted to reassess a subsample of the cohort, enabling the integration of behavioral, clinical, and dosimetric data.

This article presents a comprehensive analysis of long-term health outcomes associated with radiation exposure in the SNTS region. Specifically, we examine the prevalence of thyroid disorders, explore potential risk modifiers including lifestyle and reproductive factors, and evaluate dose-response relationships using reconstructed individual radiation doses. The goal is to generate evidence-based insights that can inform the design of sustainable public health surveillance systems in chronically exposed populations.

Materials and Methods

2.1. Cohort Description and Data Sources

This analysis is based on a cohort of 3,240 individuals who underwent thyroid ultrasound examinations between 1998 and 2002 in rural settlements of Eastern Kazakhstan located near the SNTS. Participants were selected from communities classified as potentially radiation-affected areas, using records from regional healthcare institutions.

To verify participants' current status and to collect medical data, the following sources were utilized:

- the National Mortality Registry;
- information systems of the Ministry of Health of the Republic of Kazakhstan;
- outpatient clinic medical records;
- inpatient and outpatient medical journals;
- cancer and endocrine disease registries;
- results from follow-up field examinations conducted in 2023–2024.

2.2. Questionnaire Survey

To identify non-radiation-related risk factors, a structured survey was administered in 2023–2024 among 1,099 surviving members of the cohort. The questionnaire covered the following domains:

- thyroid disease history and treatment (hormone therapy, surgical interventions);
- lifestyle characteristics (tobacco use, alcohol consumption);
- reproductive history in women (number of pregnancies, age at menarche, and menopause);
- migration history (residence during atmospheric nuclear testing).

2.3. Clinical Indicators

Data on thyroid and other endocrine diseases were extracted from official medical records and validated by certified endocrinologists. Diagnoses were classified according to ICD-10 codes. The primary diagnostic categories included:

- nontoxic diffuse goiter (E04.0), multinodular goiter (E04.2), solitary thyroid nodule (E04.1);
- autoimmune thyroiditis (E06.3);
- hypothyroidism (E03 and subcodes);
- thyrotoxicosis (E05.0);
- thyroid cancer (C73 and C73.9);
- type 2 diabetes mellitus (E11);
- obesity (E66 and subcodes).

2.4. Radiation Dose Estimation

For 2,713 participants (83.7% of the cohort), individual thyroid radiation doses were reconstructed based on the following parameters:

- age at the time of exposure;
- geographic location of residence;
- dietary patterns (particularly the consumption of milk and dairy products);
- deposition data for radioactive iodine isotopes.

Dose calculations employed the ECOSYS-87 radioecological transfer model [9], along with region-specific adaptations [4,10]. Both external gamma radiation and internal exposure due to radionuclide incorporation were considered.

2.5. Statistical Analysis

All statistical analyses were performed using the R software environment (version 4.3.0). Descriptive statistics, logistic regression, and multivariate analysis were applied to assess the association between radiation dose and endocrine morbidity. Odds ratios (ORs) with 95% confidence intervals (CIs) were computed. A p-value of less than 0.05 was considered statistically significant.

Results

Cohort Monitoring Database

An electronic database was developed to support long-term health monitoring of individuals exposed to radiation in the Semipalatinsk region. The dataset included 3,240 participants who underwent thyroid ultrasound examinations between 1998 and 2002. By the time of the most recent follow-up, 1,099 individuals (33.9%) were confirmed to be

alive, allowing for renewed data collection via structured questionnaires and clinical reassessment.

The database incorporated key demographic identifiers, as well as detailed information on residence history and migration patterns – essential for accurate reconstruction of individual radiation exposure. This structure enabled comprehensive longitudinal analysis of health outcomes in high-risk subgroups within the cohort.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Sysid	Gender	Ethnicity	Date of birth	Vital status	Date of last information	Cause of death	Profession	Settlement 1	Settlement code	Settlement status	Entry date 1	Departure date 1
149	4002	2	2	02.08.1949	3	31.12.2015		1	KANONERKA	1	1	02.08.1949	31.12.1966
150	4024	2	2	12.01.1947	3	31.12.2005		1	KANONERKA	1	1	12.01.1947	31.12.2005
151	4065	2	6	09.12.1945	2	27.02.2021	I11	1	UKRAINA	3	2	09.12.1945	31.12.1959
152	4092	2	2	11.09.1940	2	05.06.2015	E66	1	KANONERKA	1	1	11.09.1940	05.06.2015
153	4120	2	2	30.07.1930	2	17.06.2014	I67.2	1	KANONERKA	1	1	30.07.1930	17.06.2014
154	4130	2	2	07.12.1936	2	02.02.2014	I25.8	1	SEMIYARKA	1	1	07.12.1936	31.12.1958
155	4140	2	2	25.05.1932	2	29.01.2021	G93.8	1	KANONERKA	1	1	25.05.1932	23.09.2002
156	4141	1	2	02.05.1931	2	20.07.2013	C38.3	1	KANONERKA	1	1	02.05.1931	04.04.1951
157	4147	2	2	16.07.1949	2	11.11.2005	I11	2	KANONERKA	1	1	16.07.1949	11.11.2005
158	4149	2	3	11.03.1938	1	20.07.2023		1	RUSSIA	3	1	11.03.1938	31.12.1948
159	4154	2	2	10.06.1942	3	31.12.2005		2	KANONERKA	1	1	10.06.1942	31.12.2005
160	4158	1	2	10.12.1948	2	01.12.1998	I21	1	KANONERKA	1	1	10.12.1948	01.12.1998
161	4170	2	2	13.04.1942	1	20.07.2023		1	KANONERKA	1	1	13.04.1942	20.07.2023
162	4176	2	2	05.09.1947	3	25.09.2002		1	KANONERKA	1	1	05.09.1947	25.09.2002
163	4216	2	2	29.09.1935	1	17.07.2023		1	PAVLODAR REGION	3	1	29.09.1935	31.12.1944
164	4221	2	2	29.08.1941	1	17.07.2023		2	KANONERKA	1	1	29.08.1941	31.12.1960
165	4267	2	2	01.07.1938	2	05.07.2018	I20.8	1	KANONERKA	1	1	01.07.1938	05.07.2018
166	4298	2	2	20.03.1930	2	09.10.2013	I25.8	1	KANONERKA	1	1	20.03.1930	09.10.2013
167	4323	2	2	21.09.1931	2	01.01.2015	G20	1	RUSSIA	3	1	21.09.1931	31.12.1952
168	4359	2	2	15.06.1930	2	09.10.2002	I11.0	1	KANONERKA	1	1	15.06.1930	09.10.2002
169	4370	2	2	11.11.1939	1	17.04.2023		2	BELOKAMENKA	2	1	11.11.1939	31.12.1948
170	4373	1	2	01.09.1938	1	17.04.2023		1	KANONERKA	1	1	01.09.1938	03.12.1957
171	4426	2	2	09.03.1930	2	11.10.2004	I24.9	1	KANONERKA	1	1	09.03.1930	11.10.2004
172	4446	2	2	12.04.1936	2	17.10.2015	C73	1	KANONERKA	1	1	12.04.1936	17.10.2015
173	4474	2	2	20.09.1935	2	07.04.2000	I21	1	KANONERKA	1	1	20.09.1935	07.04.2000
174	4556	2	2	22.04.1949	1	17.07.2023		2	KANONERKA	1	1	22.04.1949	17.07.2023
175	4586	2	2	15.04.1949	1	19.07.2023		1	KANONERKA	1	1	15.04.1949	31.12.1985
176	4587	1	2	02.08.1947	2	08.07.2020	I49	1	KANONERKA	1	1	02.08.1947	22.10.1966

Figure 1. Structure of the "Study Cohort" database used for long-term health monitoring.

This updated dataset provided the groundwork for the next stage of the study, which aimed to capture comprehensive behavioral and clinical insights via a structured survey.

Questionnaire-Based Monitoring

During this phase, all living members of the cohort (n = 1,099) were surveyed (Table 1). The questionnaire was designed to capture:

– personal and familial history of thyroid disorders;

– lifestyle factors (tobacco use, alcohol consumption);

– reproductive history in women.

Survey analysis revealed the following:

– 63% of respondents reported a physician-diagnosed thyroid disorder;

– 33% had received thyroid hormone replacement therapy;

– 2% had undergone thyroid surgery;

– 21% reported regular smoking, and 34% reported regular alcohol consumption;

– 96.2% of female participants had experienced at least one pregnancy, an important parameter for assessing hormonal risk factors.

The survey also revealed the presence of two main ethnocultural subgroups within the cohort, each exhibiting specific dietary habits and behavioral traits. These distinctions may influence both radiation-related and metabolic health risks, serving as potential modifying factors in exposure outcomes.

Integration of Survey and Dosimetric Data as a Component of Sustainable Regional Monitoring

One of the most informative aspects of this long-term study is the ability to link reconstructed individual thyroid radiation doses with personal health histories reported through the survey. This integration offers insight not only into the overall burden of thyroid disease but also into how behavioral and demographic factors may influence health outcomes in the context of radiation exposure.

Figure 2 illustrates the observed association between dose categories and self-reported thyroid conditions, including hormone therapy use. These findings highlight the value of stratifying participants by dose when interpreting long-term epidemiological data, and they support the effectiveness of this combined approach for guiding regional health monitoring strategies.

Even decades after radiation exposure, a significant portion of the surveyed population remains actively engaged in monitoring their thyroid health. According to the survey, 63% had been diagnosed with a thyroid disorder, and 33% had received hormone therapy, reflecting a sustained awareness of health risks and access to care.

The subgroup with reconstructed thyroid doses between 100 and 300 mGy – comprising 36.9% of the cohort proved particularly informative. Within this group, thyroid disorders and hormone use were reported at elevated rates, further supporting the link between radiation exposure and endocrine outcomes.

These results demonstrate the practical utility of structured questionnaires in long-term cohort studies and support the continued investment in regional health monitoring programs for chronically exposed populations.

Table 1.

Distribution of responses to key questionnaire items (n = 1,099).

Survey Question	Response Option	Number of Respondents (n)	% of Total
Have you been diagnosed with a thyroid disorder?	Yes	692	63.0%
	No	363	33.0%
	Do not remember	44	4.0%
Have you taken thyroid hormone medication?	Yes	363	33.0%
	No	725	66.0%
	Do not remember	11	1.0%
Have you undergone thyroid surgery?	Yes	22	2.0%
	No	1,077	98.0%
Have any of your close relatives had thyroid disease?	Yes	22	2.0%
	No	802	73.0%
	Do not know / Do not remember	275	25.0%
Have you ever smoked regularly?	Yes	231	21.0%
	No	868	79.0%
How often did you consume alcoholic beverages?	Once a month or less	242	22.0%
	2–3 times per month	88	8.0%
	Once a week	33	3.0%
	Several times a week	11	1.0%
	Do not consume alcohol	725	66.0%
How many pregnancies have you had? *(females only, n = 790)*	0	30	3.8%
	1	67	8.5%
	2	246	31.1%
	3	177	22.4%
	4	107	13.6%
	5	106	13.4%
	6	21	2.6%
	7	22	2.7%
	8		
	9	7	0,9

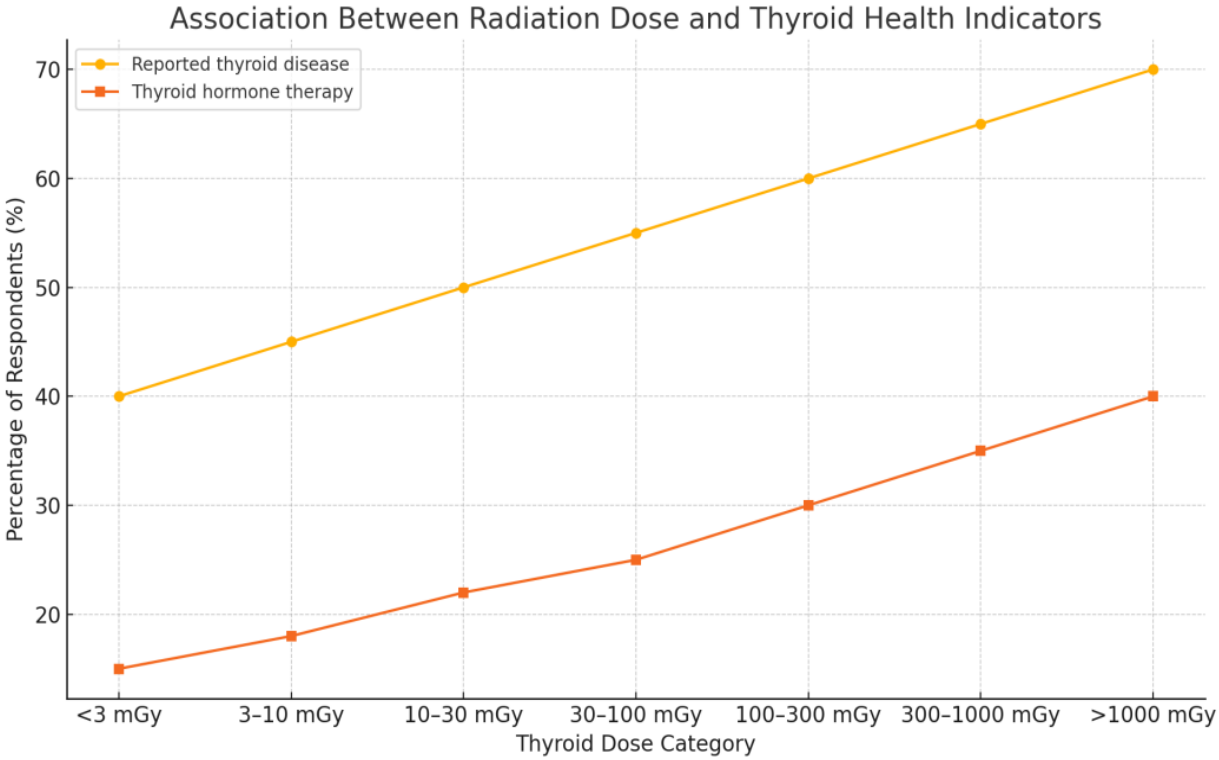

Figure 2. Association between thyroid radiation dose levels and self-reported survey indicators.

Discussion

This long-term observational study of a population exposed to radiation near the SNTS has generated a unique dataset encompassing demographic, clinical, behavioral, and dosimetric parameters. Such a comprehensive approach to health monitoring in radiation-affected communities remains rare in global practice, particularly considering the duration of follow-up, the inclusion of multiple generations, and the integration of diverse data sources, including medical registries, survey responses, and individualized dose reconstructions.

The survey findings, corroborated by official medical records, revealed a high prevalence of thyroid pathology: 63% of respondents reported a thyroid disorder, and 33% had received hormone therapy. These observations are consistent with findings from major cohort studies conducted after the Chernobyl disaster, which also demonstrated elevated rates of goiter, hypothyroidism, and autoimmune thyroiditis decades after exposure, especially among those irradiated during childhood [6,12,13].

A major strength of this study is the capacity to cross-reference survey data with reconstructed thyroid radiation doses. The highest prevalence of thyroid disorders and hormone use was observed among participants with doses in the 100–300 mGy range, confirming a dose-dependent effect previously documented in populations exposed during nuclear testing in French Polynesia [3], the Marshall Islands [7], and Belarus [2].

Unlike acute nuclear accidents such as Chernobyl or Fukushima, the SNTS population experienced protracted radiation exposure under peacetime conditions. This distinguishes the present study and enhances its relevance for understanding the effects of chronic low- and moderate-dose exposure. While the French Polynesian population shares a similar exposure context, the Kazakh cohort is notable for its methodical, multicomponent approach—leveraging historical data, medical registries, structured surveys, and radiation transport modeling to yield robust and reliable results [1,14].

An additional contribution of this study is its attention to modifying factors such as smoking, alcohol use, sex, age at exposure, and ethnocultural differences in diet and residential patterns. As demonstrated herein, these variables play a critical role in shaping long-term radiation health effects and must be integrated into screening and monitoring frameworks.

In summary, the findings from this extended health surveillance program highlight the importance of a multidisciplinary approach combining epidemiological tools, clinical diagnostics, registry analysis, and dosimetric modeling for assessing delayed health effects in radiation-exposed populations. Such strategies should serve as a model for developing regional public health responses in other territories affected by environmental radioactive contamination.

Conclusion

Long-term monitoring of the population exposed to radiation near the Semipalatinsk Nuclear Test Site demonstrated the high utility of an integrated approach that combines structured surveys, diagnostic evaluations, and dosimetric assessments. A high prevalence of thyroid disorders was identified, and a clear association with radiation dose levels was confirmed. These findings underscore the critical importance of sustainable regional health surveillance programs and offer a potential model for implementation in other areas affected by radiation exposure.

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Conflict of Interest

The authors declare no conflicts of interest. This manuscript has not been published previously and is not under consideration for publication elsewhere.

Authors' contribution

All authors contributed equally to the conceptualization, methodology, data analysis, and manuscript preparation. All authors have reviewed and approved the final version of the manuscript.

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