



CANADIAN
JOURNAL
of UNDER
GRADUATE
RESEARCH

RADIOAKTIV

In the dark

“A significant quantity of the literature surrounding nuclear reactors is considered either high-level government security or proprietary information such that it is publicly inaccessible.” (p.38)

MAY 2022 VOL 7(1)

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Remote care

“Many cancer patients currently rely on in-person support and, therefore, research aimed towards studying the best alternatives when in-person programming is simply not possible has become a priority issue.” (p.11)

Seeking refuge

“Reviewing the existing mental health infrastructure and support in place for South Sudanese refugees in Uganda, there is evidently limited mental health and psychosocial support available at an institutionalized level” (p.22)

CANADIAN JOURNAL *of* UNDERGRADUATE RESEARCH

*A student-led publication that aims to highlight
research by undergraduate students of all
disciplines*

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First Issue OF THE Seventh Volume
May 2022

COURTESY OF THE Undergraduate Research
Opportunities, University of British Columbia,
Vancouver

www.cjur.ca

ISSN: 2563-5689

This issue is published on the traditional, ancestral, and unceded territory of the Coast Salish Nations, including x^wməθk^wə́əm (Musqueam), Skw̓x̓wú7mesh (Squamish), and sə́lilwətaɬ (Tseil-Waututh).

Letter from the editors-in-chief



We are incredibly proud to present Volume 7 Issue 1 of the Canadian Journal of Undergraduate Research (CJUR), which consists of 7 unique and novel publications from talented and hardworking undergraduates all across Canada. Despite all that has happened globally over these past two years, it is heartening to see a continued influx of manuscripts from a wide range of Canadian universities, demonstrating the perseverance, ingenuity, and persistence of undergraduate researchers in these uncertain times. We at CJUR are honoured to recognize and celebrate these researchers' tremendous accomplishments by maintaining a

platform through which their work can be disseminated.

This past year, CJUR had a total of 64 manuscripts submitted to us from a range of diverse fields that reflects our journal's multidisciplinary nature, including research on educational reconciliation, agents used in magnetic resonance imaging, and even the effects of the COVID-19 pandemic on various demographics. Among these, 13 articles have made it through the peer-review process, and the remainder of the active manuscripts are still in the care of our editors, reviewers, and copyeditors. Of course, none of what CJUR does would have been possible without every author who has entrusted CJUR with publishing their hard work, as well as every reviewer who has volunteered their time and expertise to our peer-review process; for this, we thank each and every one of you for your tireless work.

Volume 7 Issue 1 marks the final publication of the 2021-2022 academic year and a transition to both a new editor-in-chief and editorial board. As such, we would like to express our immense gratitude to each and every member of our 2021-2022 editorial board, for nothing we've accomplished this past year would have been possible without their dedication, passion, and enthusiasm. Despite the fact that our collaborations had to take place online, it was a great privilege to have led such a dynamic, positive, and cohesive team, and to see how much CJUR has grown this year. We look forward to seeing CJUR continue to expand and increase accessibility to publishing for undergraduates under the direction of the 2022-2023 team, and wish them the best of luck with the upcoming year! To everyone else, we thank you for your continued support throughout the years, and we hope that you enjoy Volume 7 Issue 1.

Yours sincerely,

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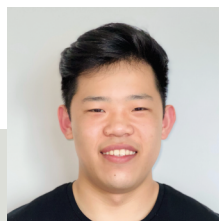
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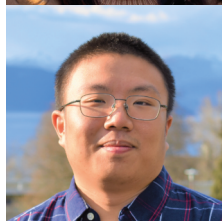
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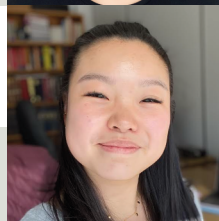
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College student study habits: Initial patterns and implications

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ABSTRACT This paper investigated whether or not there were any consistent patterns in the study habits of college students and whether or not college students studied differently than university students. Results showed that high-achieving students self-reported coming to class regularly, and they frequently used elaborative study techniques (e.g., relating readings to lecture) which have been related to better memory performance in previously published studies (Craik & Lockhart, 1972; Gurung, et al., 2010). However, these high-achieving students were still weak in their use of metacognitive skills in their studying (e.g., reviewing the questions they answered incorrectly). These results were compared to a study by Gurung et al. (2010), which used the same questions as this study to identify patterns. The comparison between university and college students is an important first step in better understanding how different types of students study and whether the effectiveness of their strategies differ. Future research should replicate this study using a larger sample of college students.

INTRODUCTION

Both students and instructors are interested in better understanding how learning works and the techniques which can be used to improve learning and/or the long-term retention of information. For students, successful learning ultimately means being able to recall information effectively during assessments, leading to higher grades and other potential benefits such as scholarships. For faculty, understanding how learning works allows for more effective delivery of content to students, resulting in a more permanent retention of course content. Consequently, being able to describe how students prepare for tests and exams (which continue to be the most common type of assessment in many disciplines) is important.

The most effective studying habits have been summarized in previous research (Gettinger & Seibert, 2002; Miyatsu, 2018; Rivers, 2020), which have proposed that students must have a vast repertoire of study strategies and the metacognitive maturity to know where, when, and how to use them appropriately. Metacognition is a key feature of students' studying and refers to being aware of and understanding one's own thinking and learning behaviours (Rivers, 2020). Students engaged in this type of reflection prior to studying significantly increased their performance (Chen et al., 2017). Furthermore, students with lower grades tended to have fewer metacognitive abilities (Coutinho, 2007; Eskandari et al., 2020; Rani & Govil, 2013). We sought to determine the extent to which students are currently using metacognition as part of their learning toolkit, specifically in preparing for tests and exams. The present research documents how a small group of high-achieving college students are currently studying.

Based on previously published studies, the process of retrieval seems to be a key aspect in long-term learning because it allows a process similar to memory consolidation to occur (Antony et al., 2017; Dunlosky et al., 2013; Larsen, 2018; Roediger & Karpicke, 2006). A student's memory of information can be greatly increased by retrieval practices, which involves repeatedly retrieving information in order to strengthen the memory (Karpicke & Roediger, 2008; Roediger & Butler, 2011). In Karpicke and Roediger's (2008) research, they looked at how different methods of repeatedly studying would affect a student's retrieval ability. They showed that when learning foreign language vocabulary, studying by re-testing oneself led to better performance compared to re-studying the material without testing. In a similar experiment, they also showed long-term retention one week later when students spent time testing themselves on the information from a passage on an unfamiliar topic (Roediger & Karpicke, 2006). These findings agree with a recent meta-analysis (Adescope et al., 2017) which demonstrated that retrieval practice leads to better retention, especially for

Published online
May 31, 2022

Citation

Weber, I.; Kennette, L. N. (2022). College student study habits: Initial patterns and implications. *CJUR*, 7(1), 6-10.

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students with low working memory capacity (Agarwal et al., 2016).

Some test preparation behaviours seem to predict better test performance, including memorising notes, making up examples, reading textbooks, reading class notes, using mnemonics, and taking practice tests (Adesope et al., 2017; Agarwal et al., 2017; Gurung, 2005). In previous research, taking practice tests in advance of tests or exams appeared to be one of the strongest predictors of exam performance, but was reported to be the behaviour least frequently used by students (Agarwal et al., 2017; Gurung, 2005).

Two other study behaviours that students often engage in is highlighting and re-reading course material. The effect of highlighting and re-reading material on student performance has been inconsistent in the literature (Dunlosky et al., 2013); it may lead to lower performance (Gurung et al., 2010) or an insignificant effect on student performance (Gurung, 2005). These techniques have been reported as frequently used by many students, regardless of their effectiveness (Dunlosky et al., 2013; Gurung et al., 2010).

A recent article by Gurung (2005) focused on students' studying behaviours and examined whether these behaviours enhanced or hindered their performance. Gurung noted that there is much research regarding how students ought to be preparing for exams (e.g., elaboration) but little research on how students are actually preparing. The researcher provided a survey to a class of introductory psychology students at an American university to identify the learning methods that the students in this class were using, as well as the length of time they were using each method. Gurung (2005) discovered that many of the most effective studying techniques were not the methods most commonly used by students. This study by Gurung (2005) also found that more hours spent studying did not necessarily lead to higher exam scores. The methods that appeared to work best included creating examples, reading books and notes, retrieval practice, using mnemonics, thinking of real-life examples, and self-testing (Agarwal et al., 2017; Dunlosky et al., 2013; Gurung, 2005; Miyatsu, 2018).

In a follow-up study by Gurung et al. (2010), university students most often reported attending class, organising their notes, writing down relevant numbers, and knowing assignment due dates, as study techniques used. The least frequently reported behaviours included using the textbook website for practice tests and asking for additional learning material from the instructor. Some of these study habits (e.g., answering all questions on the study guide, using practice exams, attending every class, explaining problems using the material) predicted better student performance on the final exam whereas others (e.g., looking over notes after class, highlighting important information, asking friends/classmates to re-explain material, asking the professor or TA for additional material) did not affect performance or predicted worse performance. It is also noteworthy that some of the studying behaviours that had the strongest positive correlations with final exam scores were the least frequently used by students (Gurung et al., 2010; Miyatsu et al., 2018).

College students (i.e. students who are typically pursuing a two-year credential) and university students (i.e. pursuing a four-year

undergraduate degree) are different in important ways. For example, college students are more likely to be juggling family or other responsibilities and less likely to use (or be aware of) digital success tools (Gierdowski, 2019). They are frequently less aware of their mental health issues and needs (Katz & Davison, 2014), and other social, psychological, and economic variables (Miller et al., 2004) that affect the way they learn. Additionally, different programs might lend themselves better to certain test-preparation strategies (Gurung et al., 2020). Given that colleges and universities offer different types of programs (applied versus theoretical), it stands to reason that students may be using different strategies to study. Because research on Canadian college students is rare, American data has been presented throughout this paragraph to support the claim that college and university students differ in important ways. Our research fills this important gap in the literature: describing learner characteristics of the Canadian college student. To date, no studies exist examining students' studying behaviours in Canadian colleges. College student data is infrequently solicited as most researchers primarily rely on university student samples. Many experts in the field have called for more diversified samples in research (Henrich, 2020; McCann et al., 2019). It is important to include college-level students in research because the absence of data results in (possibly) less generalizable results about how post-secondary students learn. By describing a college student sample, we can better understand how students in general prepare for assessments and perhaps be in a better position to support effective student learning in colleges. There appears to be some consistency in which study behaviours lead to better student outcomes or higher grades among university students (Chen et al., 2017; Dunlosky et al., 2013; Ekuni et al., 2020; Gettinger & Seibert, 2002; Gurung, 2005; Gurung et al., 2010; Karpicke & Roediger, 2008). It is instructive to identify which of these behaviours college students are engaging in and whether or not students are engaging in different study habits compared to university students.

The first goal of this project was to describe how Canadian college students were preparing for tests and exams and any consistent patterns arising. Additionally, we aimed to compare the study patterns of college students with those of university students, described in previously published research by Gurung et al. (2010).

METHODS

Participants

All participants were registered students in a general education course in an Ontario college. In Ontario, the term "college" is used to designate institutions of higher education that grant 1-year certificates as well as 2- and 3-year diplomas. In an introductory psychology course, we successfully recruited a small number of students ($n = 6$) to participate in an online survey. We also collected their final grades at the end of the semester. No other demographic data was collected in order to protect student privacy.

Materials and procedures

Following a consent form, students were invited to go online, outside of class time, and fill out a survey about their study habits and behaviours (Study Behavior Checklist in Gurung, et al., 2010), which they rated on a five-point scale from 1 (Not at all like me) to 5 (Exactly like me). Several areas shown to relate to student studying success were included in the checklist, including items

related to student organisation, the ability to apply material, elaborating on content, metacognitive abilities, and resource use. The 35-item questionnaire included items such as “I highlighted the most important information in each chapter to review later”, “I crammed before this exam”, and “I went to the book website for practice quizzes”. At the end of the semester, the survey responses and final grade were combined and analysed. Each student was identified by a code that preserved anonymity.

This data was used to determine the extent to which participants reported using each study behaviour. We examined the qualitative data for trends and patterns, focusing on the behaviours students reported using most and least often.

RESULTS

Due to the small sample size, the results have limited generalisability to students on a whole and should be interpreted with caution. Although many students signed the consent form to release their grades to the researchers (N = 18), only 6 students completed the associated survey in which they identified their study habits. With the exception of one outlier (which was removed from the data presented here), all students who participated in the survey were high-achieving students (>80%). The data from this outlier was omitted because their final grade in the course was more than 3 standard deviations below the mean and, therefore, was different enough from the rest of our sample to warrant its removal.

The results presented here describe student studying behaviours using the Likert scale from 1 (Not at all like me) to 5 (Exactly like me). We interpreted a score of 4 or 5 to mean that the student typically engaged in that behaviour and scores of 1 or 2 to indicate that they did not typically use that strategy to prepare for tests and exams. A summary of student responses is shown in Tables 1 & 2. The most frequently endorsed items included: “I attended every class”, “I answered every question on the study guide”, and “I evaluated the pictures/photos in the book”. Students did not report using the following behaviours very frequently: “I varied my studying behaviours by switching between reading, rehearsing, solving problems, writing, etc.”, “When I got an answer wrong on a quiz, I went back to the related material to better study it”, “I went to the textbook website for practice quizzes”, “I took the online quizzes without any notes”, “I asked (by email, a phone call, visit, etc.) the professor to explain material I did not understand”, and “I briefly reviewed all the chapters covered before I studied”. Therefore, our sample of college students self-reported engagement with the imagery in the textbooks and PowerPoint presentations, as well as class attendance. Comparatively, our college student sample used strategies involving metacognitive skills and external resources less frequently, including contacting the professor and taking practice quizzes. Given our small sample size, no quantitative statistical analyses beyond mean and standard deviation calculations were performed.

Table 1 Summary of highest-scoring items on a list of study behaviours in college students.

Question	Mean	SD
I related what I was reading to lecture materials and discussion.	4.17	0.84
I attended every class.	4.33	0.55
I evaluated the pictures/photos in the book.	4.50	0.89
I answered every question on the study guide.	4.67	0.89

Table 2 Summary of lowest-scoring items on a list of study behaviours in college students.

Question	Mean	SD
I varied my studying behaviours by switching between reading, rehearsing, solving problems, writing, etc.	2.00	1.73
When I got an answer wrong on a quiz, I went back to the related material to better study it.	2.17	1.34
I went to the textbook website for practice quizzes.	2.30	1.67
I took the online quizzes without any notes.	2.33	1.67
I asked (by email, a phone call, visit, etc.) the professor to explain the material I did not understand.	2.50	2.19
I briefly reviewed all the chapters covered before I studied.	2.50	1.30

DISCUSSION

There were notable similarities in study techniques used between the present research and the Gurung et al. (2010) investigation. The overlapping techniques included taking down and organising notes, creating examples about the material, reviewing the provided reading materials, and using a provided study guide. This seems to indicate that some techniques are more commonly used among students, regardless of institution.

Gurung et al. (2010) also presented some data that deviated from our college students' patterns (Figure 1). University students in Gurung et al.'s (2010) American sample appeared to take more notes and access additional readings more frequently than our sample of Canadian college students. Although the differences between American and Canadian students may be attributed to differences in the schooling systems in the two countries it could also be the case that students engage in different study behaviours in the two types of institutions. Our small sample of college students also appeared to prefer visual supplements (graphs, images) in the textbook compared to the previously published university data.

Metacognitive self-reflection appears to be important in successful preparation and learning, according to past research (Chen et al., 2017; Gurung et al., 2020; Rahimi & Katal, 2012; Rivers, 2020). However, our research found that high-achieving college students engaged infrequently in metacognitive study techniques. It is still undetermined whether students using metacognitive studying techniques out-perform students using other approaches to study. Future research could address the differences in metacognitive and alternative studying approaches.

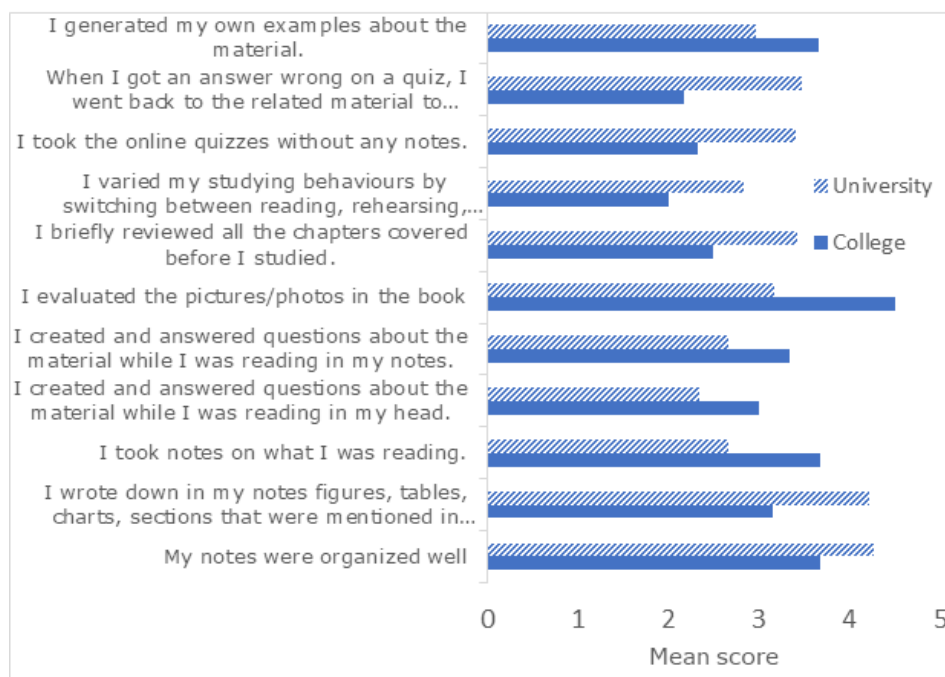


Figure 1 Comparison of university and college students' studying behaviours. Note: the university data was taken from Gurung et al. (2010) and the college data is original.

One major limitation to our study was the small sample size. All of our participants were high-achieving students, which means that they may not be representative of the college student population as a whole. Consequently, although the reported patterns are interesting, they should be interpreted with caution. It is encouraging that, in a quasi-replication, Redd & Kennette (2020) found similar patterns using a larger sample, which seems to suggest that the summary data reported herein is at least adequately representative of the larger college population. What can be concluded from these results is that the high-achieving college students in our sample appear to use similar study strategies as the much larger Gurung et al. (2010) sample of university students.

This research serves as an important initial step to identifying which study habits (high-achieving) students at a college are engaging in. Although we had anticipated correlating study habits to classroom performance, our small sample size prevented us from doing so. We would expect to find that students who frequently employ study habits that lead to deeper processing would perform better on assessments. However, this relationship has yet to be examined in college classrooms. As previously noted, there exist far fewer research studies of college students compared to university students. As such, this research is an important first step in understanding this subset of the student population better. A related shortcoming is that most samples tend to be WEIRD: Western, Educated, Industrialized, Rich, and Democratic (Henrich, 2020; Henrich et al., 2010). Future examinations of college students' studying behaviours should include a diverse sample and ensure that the sample includes students across a range of academic performance levels, not only high-achieving students. Additionally, future studies should replicate this methodology with a more diverse and larger sample population, and include grade data to examine whether the most used techniques are actually effective or whether the more under-utilised approaches to studying could be more predictive of learning.

We also recommend that faculty members inquire about the study habits of their students and ask students to complete the Study Behavior Checklist (Gurung et al., 2010) to open a discussion about the efficacy of students' learning. Simply completing the inventory could even inspire students to try new approaches to test preparation or to seek out expert guidance from faculty.

CONCLUSIONS

The methods that students use to prepare for tests and exams may not always be effective. The high-achieving students examined here did not engage in high levels of metacognition during their studying. This paper makes an important contribution in that it examined the study habits of college students, information which is not currently available elsewhere. Comparing the study habits of university and college students can help us to better understand the effectiveness of these study strategies and inform models of learning and memory.

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The impact of online programming on cancer patients

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ABSTRACT Abstract This preliminary and qualitative study examined how online cancer support programming has impacted cancer patients—specifically, the effects on their physical, mental, emotional, and spiritual well-being. We also investigated how cancer support programming could be improved from the perspectives of the participants. Due to the recent COVID-19 pandemic, many organizations have shifted to online-based approaches to allow for continued access. The sudden shift to online programming caused a significant learning curve for organization staff, volunteers, and members. This study was conducted entirely online and results were analyzed qualitatively. To facilitate this study, we recruited six participants from a Canadian cancer support organization. All six participants were between the ages of 60 and 70, a common age of members at this specific cancer support agency. Once participants were recruited, they received an informed consent form, interview questions, and a form requesting their consent to use their data through Google forms. The interview consisted of 10 questions and took approximately 30 to 45 minutes to complete. Through thematic analysis, we found five themes that reflected our participants' experiences with online programming: social connection, positive emotions, growth and gains, challenges and difficulties, and easy accessibility. Our findings showed more positive than negative outcomes of online programming; however, there were still challenges, such as participants losing the strong in-person connections they once experienced. This study is especially significant as the world moves forward through the global pandemic and in-person supports are being interrupted. Many cancer patients currently rely on in-person support and, therefore, research aimed towards studying the best alternatives when in-person programming is simply not possible has become a priority issue.

INTRODUCTION

Cancer is an ongoing concern for the Canadian population (Brenner et al., 2020). In 2020, Canada was expected to see 225,800 new diagnosed cases of cancer (Brenner et al., 2020). A cancer diagnosis comes with increased levels of physical and psychological distress (Atreya et al., 2018). To cope with such challenges, complementary and alternative therapies (CAT) have become a widespread option for those experiencing cancer. Support groups and practices such as yoga, Qi-gong, reiki, and meditation are among these complementary therapies. Edwards et al. (2014) found that cancer patients choose these therapies for a variety of physical and psychological reasons linked to general health and quality of life.

In March 2020, due to the COVID-19 pandemic, cancer patients were considered a vulnerable and high-risk population by the Canadian Government (Public Health Agency of Canada, 2020) due to disruption in their cancer care. Further, the stressors cancer patients experienced were elevated during the COVID-19 pandemic. In a longitudinal study by Turgeman et al. (2021), they found that anxiety was associated with the pandemic and that it has impacted the well-being of cancer patients in many ways, such as receiving reduced support from those close to them. COVID-19 was also associated with multiple emotions such as fear and worrying that impacted the daily life events of cancer patients (Erdem & Karaman, 2020; Miaskowski et al., 2020; Romito et al., 2020). The results of Miaskowski et al. (2020) indicated that there were clinically elevated scores of loneliness and stress related to COVID-19 that were negatively impacting sleep. In addition, Erdem & Karaman (2020) and Romito et al. (2020) found that various cancer patients had a significant fear of contracting the COVID-19 virus; thus, they would not leave their homes, falling into isolation. As a result, Erdem & Karaman (2020) recommended cancer patients receive specific and specialized support

Published online
May 31, 2022

Citation
Dhanoa, T.; Thompson, E. (2022). The impact of online programming on cancer patients. *CJUR*, 7(1), 11-17.

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throughout the pandemic, since the pandemic has resulted in significant changes in daily routines for cancer patients. The pandemic restrictions imposed by the government caused various organizations to close their doors to in-person programming. Organizations created to assist cancer patients in coping with their physical, mental, spiritual, and emotional well-being had to shift to an online-based approach to allow for continued access for their members.

Psychological support can be conducted in a variety of formats. Montali et al. (2021) noted that psychological support could be provided through online support groups, which allowed cancer patients to feel a sense of belonging and helped them gain experiential knowledge. Stressors can take the form of psychological and physical symptoms, such as pain and fatigue (Miaskowski et al., 2021). Further, Romito et al. (2020) found that 25% of patients requested online psychological support. The results of this study may initiate making online support services available for cancer patients. It is important that vulnerable populations, such as cancer patients, have access to continued support and programming. Throughout the pandemic, many cancer patients had to shift their lifestyles, which has compounded the pre-existing stressors related to their cancer diagnosis. It is even more crucial to provide stable and secure programming in a timely manner during a time of insecurity for many.

Barriers are present for cancer patients seeking support. In a study by Sansom-Daly et al. (2015), barriers included the stigma and unfamiliarity with psychology, making it difficult to trust the psychological process. A common barrier for cancer patients is living outside of the city, which can increase their risk of health problems (Frensham et al., 2018). This is seen as a common barrier because rural areas have more limited access to nearby healthcare services (Freshman et al., 2018). Most often, cancer patients are faced with cancer-related fatigue (Xu et al., 2019). Similar findings were uncovered in a study by Montali et al. (2021), in which participating in in-person groups was difficult due to either living in a rural community or the fatigue from treatment. In a study by Xu et al. (2019), fatigue was described as making the cancer recovery process significantly more challenging, resulting in reduced quality of life. Telepsychology offers an alternative to in-person treatment by offering web-based ones. In a study conducted by Wakelin & Street (2015), navigating an online environment alongside others provided the opportunity for participants to monitor their progress alongside fellow participants. Online programming has shown to increase psychotherapy and programming interactions, since web-based interventions provide accessible content to a large number of people (Kanera et al., 2017). Online programming can be especially effective in reducing barriers for cancer patients who cannot easily leave home when they are feeling unwell. Zernicke et al. (2016) explored the online impacts of the Mindfulness-Based Cancer Recovery (MBCR) psychosocial program. This program is often facilitated in person. However, in this study, Zernicke et al. (2016) adapted the program to an "online real-time synchronous format" (p.1071). The results of the study showed that the online intervention of MBCR had beneficial effects in reducing the negative mental symptoms that many cancer patients are faced with and increasing spirituality in younger participants (Zernicke et al., 2016). Overall, through active participation in the MBCR program, participants reported an increased sense of belonging and tranquility (Zernicke et al., 2016). Much of the research

surrounding online delivery of support programs for vulnerable populations is promising (Wakelin & Street, 2015). In conclusion, online programming has been shown to help decrease the psychological and physical barriers to health support.

There is a significant amount of psychological distress in cancer patients, such as anxiety and/or depression during cancer diagnosis and treatment. Receiving a cancer diagnosis increases psychological and physical burden (Agboola et al., 2015). This burden can carry over not only to the patient but also to their families, leading to poor mental health outcomes (Wang et al., 2017). Over the years, more therapeutic opportunities have become available to cancer patients to focus on their quality of life and connect with others. Cleary & Stanton (2015) noted, upon completion of a psychosocial workshop, that breast cancer patients experienced increased levels of self-confidence. Further, the shift to online programming has psychologically benefitted cancer patients in various ways. A study by Zernicke et al. (2016) found an increase in physical and psychological wellbeing caused by an online mindfulness-based cancer recovery program. Several cancer patients have opted for alternative and complementary therapies that help them meet their psychological needs with an emphasis on providing hopefulness and control regarding their cancer diagnosis (Edwards et al., 2014). Additionally, Cleary & Stanton (2015) found that participation in an online psychosocial intervention led to decreased levels of loneliness and, as a result, decreased levels of depressive symptoms. Research shows that online programming positively impacts cancer patients as it continues to decrease stressors and improve quality of life.

In our preliminary research, we investigated the impact of online programming that was unexpectedly brought about by the COVID-19 pandemic on cancer patients. Specifically, we focused on the effects on their physical, mental, emotional, and spiritual well-being through a thematic analysis of the perspectives and stories of individuals diagnosed with cancer. The goal of our research was to evaluate the effectiveness of online programs through the feedback of its participants. The feedback provided insight into the strengths and weaknesses of the online programming that was offered.

Participants were asked how they have benefitted from online programming and to indicate which aspects of programming they would like to see continued post-pandemic. We anticipated that participants would report mainly positive experiences with online programming based on our literature review. Our goal was to produce useful suggestions for programs to be offered online in the future based on participants' perceptions and experiences.

METHODS

Participants

Six participants were recruited for this study. The sample size was limited, but the insight shared by participants remains valuable. Participants were recruited through a local cancer support organization. Due to confidentiality concerns, the cancer support organization will not be named. According to the Canadian Cancer Association (2019), cancer is diagnosed most often within the age group of 65 to 69 years old. In our study, the participants ranged from 62 to 70 years old. Although this study did not have a wide age range, the ages of the participants in this study are consistent with the age group that is most often diagnosed with

cancer in Canada. The participants comprised of three females, two males, and one unidentified. The participants were from a variety of ethnicities including Chinese, Canadian, French, Scottish, German, English, Ukrainian, Caucasian/White, and Metis. The participants were members of the organization for a minimum of two years and had participated in both online and in-person programming. All participants signed an informed consent form which informed them that their participation was voluntary and that they could exit or decline from participating at any time.

Role of Researchers

As researchers, we acknowledged that we needed to be aware of collective and personal biases, beliefs, and opinions when conducting qualitative research. To do so, the responses were debriefed among two different researchers and any underlying assumptions were discussed and reflected upon. Each researcher also individually participated in a self-reflection process about how each person felt about the questions and responses. The questions were tailored to allow for open interpretation and to focus specifically on an unbiased evaluation of the program itself.

Interviews

An initial step of the study was to contact the six participants through email to ensure that they were interested in participating in the study. For this study, we conducted a thematic analysis to categorize the perspectives of the participants into themes. A thematic analysis allowed us to elaborate and explain the themes that arose in the data. We followed the Braun & Clarke (2006) method to analyze the results of this study. As Braun & Clarke (2006, p.94) stated, in a thematic analysis, the following questions

need to be answered:

1. "What does this theme mean?"
2. "What are the assumptions underpinning it?"
3. "What are the implications of this theme?"
4. "What conditions are likely to have given rise to it?"
5. "Why do people talk about this thing in a particular way?"
6. "What is the overall story the different themes reveal about the topic?"

Using these questions as a guide, we worked through the six phases recommended by Braun & Clarke (2006) to establish accurate and complete themes. To begin this process, we compiled the data using Microsoft Excel and Word Documents. During this initial phase, we organized the data to review the transcriptions five times. During each reading and review, we noted revealing patterns and ideas present in the data, most notably surrounding social connection and how to navigate it in a virtual setting. Next, we assigned initial codes and labels to the data to build the analysis and create categories. This step was performed by pulling out codes and turning them into categories in order to outline the themes. Before defining the themes, we reviewed the data to ensure accuracy in relation to our codes and categories. We clearly named the themes by ensuring that they accurately captured the stories of our participants. The themes that arose in this study are social connection, positive emotions, growth and gains, challenges and difficulties, and easy accessibility. These themes allowed us to create a comprehensive research report surrounding online programming (Figure 1).

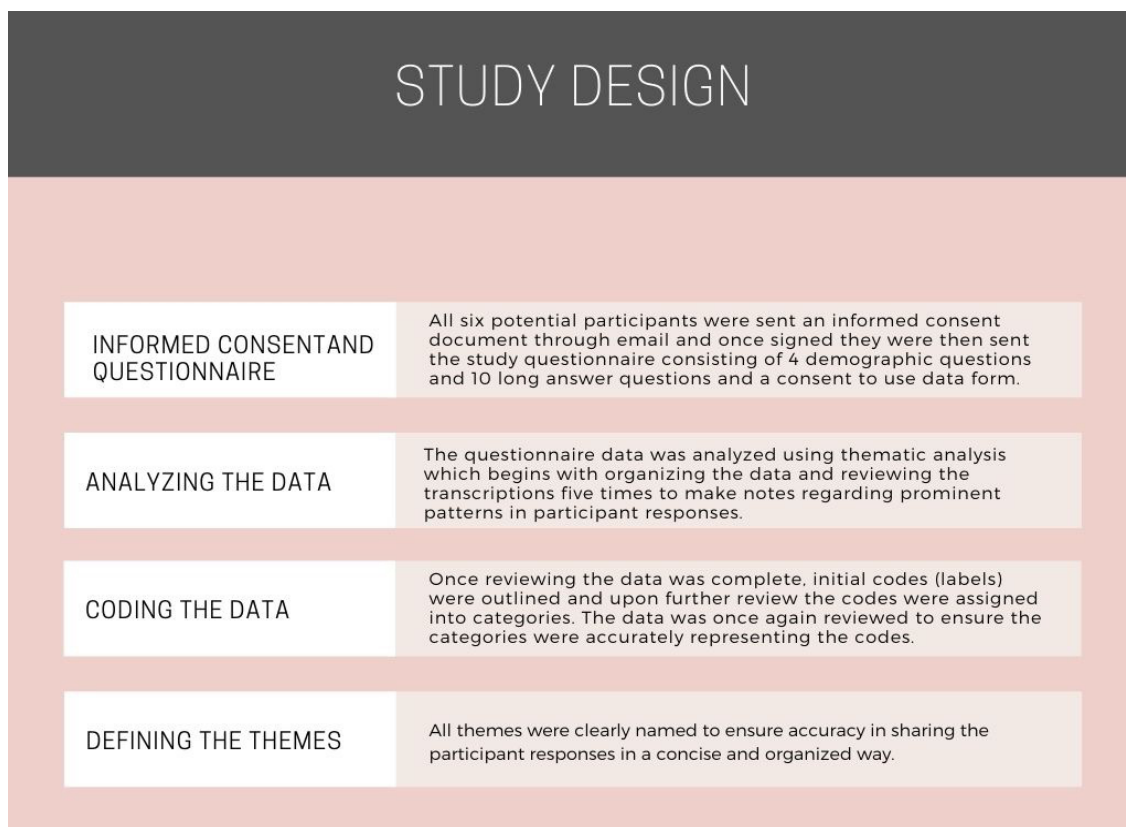


Figure 1 Study Design. This figure is a visual aid to clearly show the study design employed. The simplicity of this study design did not take away from the data being analyzed in a variety of formats. The data used was straight from the virtual questionnaires all six participants were emailed, and we kept their direct quotes throughout the entire thematic analysis process. The data was first read and re-read multiple times to ensure that nothing was missed in the note-taking process. The data was then taken through a process of coding where each relevant quote was labelled and placed into categories. These categories were reviewed to ensure accuracy from the quotes used to build each category. Finally, the categories were divided into specific themes that were used for the results section of this study, and a final check was done to ensure that the themes portrayed the participants' stories in an accurate fashion.



Figure 2 *Social Connection*. This figure consists of four direct quotes provided by the participants in this study through the questionnaire process. Social connection was the most recurring theme within this study with five out of six participants ($n = 5$) mentioning multiple times either that they missed the in-person connections or that, even online, feeling connected to others was important throughout their cancer journey and the pandemic. Two of the quotes in this figure show that a large component of social connection was being around others who understood what they were going through. Overall, these four statements are positive, but participants still missed previous in-person connections. Online programming was deemed a suitable candidate for social connections when in-person interactions were not available.



Figure 3 *Positive Emotions*. This figure consists of four quotes taken directly from the participant responses in the questionnaire. Positive emotions meant something different for each participant and, here, we see that it can come in the form of being uplifted, a feeling of something to look forward to, and feeling included. Positive emotions also took the form of believing that they benefited from the classes in some way, whether it was physically, mentally, spiritually, or other. These statements are all positive and all six of the participants in this study shared positive emotional responses at some point throughout the study with regard to online programming, particularly expressing that they benefited from the programs.



Figure 4 *Growth and Gains*. This figure is meant to represent some of the direct quotes from participants regarding how online programming helped them grow and gain new insights/skills that they may not have had previously. Growth can mean a variety of things and, in this figure, it includes feeling more creative, learning from others, trying new things, and finding a new perspective for the world. All of these statements are positive as participants used words such as “encourages”, “inspired”, “allow” and “it helped”. All six participants had statements throughout the study that either indicated signs of personal growth or gains from the programs.

RESULTS

Social Connection

Social connection was a significant and common theme among almost all participants in this study. Participants often reported that they felt uplifted in the programming and enjoyed meeting others who were on the same journey as them. Three participants ($n = 3$) out of six mentioned that the social connection came from being with others rather than performing the actual program activity such as felting or photography. For others, social connection came in the form of being around others who were on a similar journey, which created a deeper support system. Most notably, participants mentioned that online programming was a good option in the face of the pandemic but could not fully replace the social connections made in person. Four participants ($n = 4$) expressed missing the close contact with others (Figure 2).

Positive Emotions

Participants expressed positive emotions in various ways in response to online programming. The most common positive emotion expressed was that online programming had met their needs or benefited them in some way. Participants reported that online programming throughout the COVID-19 pandemic was helpful in providing direct support and allowing them to feel comfortable and uplifted. Participants also reported that the programs offered took mental and social factors into account, along with the physical symptoms of cancer. Recognizing these other factors left participants with positive emotions such as being thankful, appreciative, and supported (Figure 3).

Growth and Gains

‘Growth and gains’ was another theme that described participants noticing changes in themselves during their online programming experiences. The largest portion of this theme was ‘learning’, as four participants ($n = 4$) noted that programs allowed them to learn new skills and learn from others. Three participants ($n = 3$) noted personal growth by practicing skills learned, such as yoga, outside of program times and challenging themselves to try something new. These programs gave participants the chance to open up creatively through programs such as photography. Given the online environment, there was also growth in confidence using technology. Combined, the growth from these online programs comprised physical, mental/emotional, and spiritual gains (Figure 4).

Challenges and Difficulties

Although the majority of responses were positive, there were still some challenges and difficulties that arose. Online programming was a new approach for staff, volunteers, and members. One of the challenges presented was that programs were less personal than traditional in-person programs, with instructors unable to give individual feedback and members not being able to speak with each other on the side. One participant ($n = 1$) shared that it was only difficult to follow along if it was a program that they had never done before. It was also shared by four participants ($n = 4$) that there was difficulty jumping in or fully opening up with the group. Due to online programming, short programs—such as once a week for four weeks—made it difficult to build relationships



Figure 5 *Challenges and Difficulties*. This figure is meant to be the home for the more negative and constructive statements provided by participants. Although much of this study had positive feedback for online programming, it was still a new program and could not fully replace in-person connections and experiences. Challenges and difficulties showed up in a variety of ways depending on the participants' needs. Some participants mentioned that forming strong social connections was challenging virtually, while other participants expressed that understanding the program content itself was a challenge online if they had never done it before. These challenges and difficulties were expressed in some way by five out of six of the participants in this study, further emphasizing how important social connections are for this demographic. Overall, these statements are negative but should be taken in a constructive way to help build stronger online programming in the future.

with other members and gain comfort in opening up with one another. This was primarily due to the lack of time to meet before and after each class. Lastly, two participants ($n = 2$) mentioned that, in online programming, there was less accountability to attend, participate, and engage in activities (Figure 5).

Easy Accessibility

Finally, given the focus on the online component of the programming, a common theme that occurred was easy accessibility. Five participants ($n = 5$) shared that choosing and registering in programs was an easy process. All six participants would prefer to see both online programming and in-person programming continue post-pandemic. As well, the six participants noted that online programs were more accessible because they could participate from home on their bad days. This was a common concern for many cancer patients, so it was hopeful to see that online programs have helped overcome this barrier. Regarding the pandemic specifically, five participants ($n = 5$) shared that having access to online programs during this time was a necessary aspect for supporting either their cancer treatment or recovery and kept them connected to others (Figure 6).

DISCUSSION

Our study examined the perspectives of six participants that were experiencing cancer treatment and recovery and their experiences with online programming during the COVID-19 pandemic. In addition to examining individuals' experiences, this study explored program effectiveness through the psychological, emotional, and spiritual benefits.

The results of this study were consistent with past research. Our findings suggested that the benefits of online programming included social connectedness, positive emotions, various growth and gains, and easy accessibility. Alongside the benefits of online



Figure 6 *Easy Accessibility*. This figure was generated by considering the different ways that participants view accessibility of online programming. Accessibility can come in many forms and, within this figure, there are a few examples such as more space for people to join and being able to participate from home when feeling unwell. All six participants ($n = 6$) shared similar statements expressing that there should be a place for both in-person and online programming moving forward, as online programming provides necessary accessibility for members who may not be able to leave their house or simply are not feeling well enough to participate in-person but still need the social support. Five out of six participants also felt that the process of choosing programs was easy, which made it more accessible. The responses shared a common and positive theme that online programming has helped keep individuals connected during an isolating time.

programming, participants reported challenges such as fewer personal connections.

Social connection is an important factor that is necessary in our lives. While the pandemic put individuals into isolation, participants reported that, through online programming, they gained or maintained their social support system. Similar research studies found connections increased through online experiences while also instilling peace in participants. Social connection was presented as a leading factor in online cancer support groups (Malloch & Taylor, 2018). Additionally, in the Zernicke et al. (2016) study, they found a deeper connection was built with others through the internet; although, age may play a factor. Our results showed that, regardless of age, participants found a way to connect with other individuals experiencing cancer treatment or recovery through an online platform.

Throughout our study, participants reported having various positive emotions when they participated in online programming. These positive emotions included feelings of relaxation, comfort, and thankfulness. Our theme of positive emotions was consistently found in other research studies that investigated the impacts of online programming. Glynn et al. (2020) conducted a study looking at the impacts of an eight-week online mindfulness-based program on cancer patients and found themes related to relaxation, calmness, managing stress and pain, as well as common humanity. Many of our participants reported similar positive feelings. Similarly, Kubo et al. (2018) reported that patients showed a decrease in anxiety and distress levels after they participated in an 8-week online mindfulness intervention. Our study supported the results of previous research findings that, through online programming, participants gained and maintained positive emotions.

Through online programming, participants reported personal and psychological growth—most notably, learning new skills. Participants were able to build their confidence and knowledge surrounding healthy activities. Similar results were reported in Zernicke et al.'s (2016) study, where they found that, through online mindfulness programming, personal growth improved as the participants increased their "sense of meaning, connectedness, and peace" (p.1078) with their cancer diagnosis. Through similar programs, one of our participants reported that "it helped to look at the small world at home in a different light."

Despite widespread appreciation of the online programming being offered during the pandemic, many participants expressed that they missed the in-person components. There were some notable challenges such as less accountability to participate, no extra time to talk with other participants, and increased difficulty in following along if it was a new program. Although there is not much research surrounding the challenges of online programming, further research could be done to explore how these challenges could be overcome.

In this study, many participants focused on how barriers were removed for them when programs were moved online. In a study by Montali et al. (2021), online support groups provided a place for cancer patients to gain connections that they had lost due to their cancer diagnosis. Participants mentioned the removal of barriers such as commuting on the winter roads, leaving home when symptoms were bad, and providing connection when they were isolated at home throughout the pandemic. This was consistent with previous research in a study done by Kubo et al. (2018), where the need to attend a program in-person presented as a larger barrier for those in treatment or with advanced stages of cancer. Further, similar findings were uncovered in a study by Montali et al. (2021), where joining in-person groups was made difficult for cancer patients who lived in small towns or experienced fatigue from treatments. Our results indicated that the organization's program website and Zoom platforms were easy to access and navigate, which made the online programming accessible to all participants.

Our study was presented with certain limitations that should be considered for future research. Firstly, our study included a small sample size which limited the comprehensiveness of our results. In future research, a sample size of 25 participants would be ideal to explore the experiences of cancer patients and, more specifically, determine the effect size to uncover the efficacy of online programming for cancer patients (Brybaert, 2019). Further, an ideal sample size of 25 could allow future research to exploit statistical power to determine the null hypothesis of the study (Brybaert, 2019). Our next limitation was that we were restricted to an online platform to conduct our interviews; therefore, we were unable to observe non-verbal cues and did not have the opportunity to ask immediate clarifying questions. In future research, we would conduct in-person interviews to assess all aspects of the participants' perspectives. Lastly, all participants were over the age of 60. Having a small age range could have impacted the results of this study as our results lack breadth of cancer experiences from different age groups. Therefore, we encourage future studies to have a more inclusive age range to account for experiences from participants who are in different stages of life. Conducting a study with a wide range of participant ages could allow us to discover the online programming and

psychological needs of youth, younger adults, middle-aged adults, and senior age groups and to determine if similar themes arise across age groups.

CONCLUSION

In our study, cancer patients reported connection, positivity, growth, and stability through online programming provided during the COVID-19 pandemic. This study was a preliminary study meant to explore the effects of online programming for cancer patients. Given the small sample size, limited age range, and virtual preliminary study design, the possibility for follow-up studies is important to note. Follow-up studies could include a larger sample size and a more diverse age range to increase the comprehensiveness of the study, allowing for more effective research within the field of virtual programming and cancer patients. Providing effective supports that are evidence-based is key to moving patient care initiatives forward. This area of research is relatively new and the more follow-up studies that can be conducted, the more evidence-based programs can be offered to improve patient care remotely. Rapidly changing supports can be a source of unnecessary stress for patients; therefore, establishing alternative methods for effective support can positively impact overall patient care. To further investigate the impacts of online programming in the future, we hope to look at the impacts of individual programs, such as yoga and mindfulness-based self-compassion. As the pandemic continues, engaging in research regarding online programming supports is a fundamental step towards effectively supporting cancer patients. We hope that our preliminary study can provide useful suggestions, such as promoting social connection among participants and easy accessibility, for building stronger online programming for cancer patients.

This preliminary study was supported by Concordia University of Edmonton. A big thank you to Dr. Wendy Pullin, Dr. Marilyn Hundleby, and Ryan Olfert.

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Canadian government debt and deficit spending: Towards an efficient and equitable economic recovery to the COVID-19 pandemic

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ABSTRACT Since its identification in December of 2019, every nation on this planet has faced a once-in-a-century battle against the coronavirus disease, COVID-19. As countries grappled with their own responses to the pandemic, the Canadian government spent an unprecedented amount of money to provide support to businesses that were forced to close due to lockdowns, as well as citizens who lost their jobs. 2020 saw the largest global economic downturn since the Great Depression because of these emergency measures and similar ones enacted in other countries. Government debt and deficit spending in the Canadian context is increasingly becoming a contentious political issue which warrants an extensive review of literature and past policies to map a path forward. This paper will examine austerity and Keynesianism, two political-economic policy strategies, to address the growing government debt resulting from COVID-19. Given the failures of austerity policies in alleviating economic downturns in recent crises, this paper will argue that the best strategy to address post-COVID government debt is to enact Keynesian stimulatory fiscal policy to produce economic growth. Such a strategy would provide the best economic outcome and avoid the pitfalls of austerity, which often reduces the well-being of society by cutting social programs and promoting class and gendered inequality. The pandemic has exposed shortcomings in the current economic and welfare systems reinforced by neoliberal austerity. These shortcomings have not only been exacerbated by the pandemic, but also risk hindering a more efficient and equitable recovery. This review is aimed at stimulating more research into modern applications of Keynesian fiscal policy to produce better responses to economic crises now and in the future.

INTRODUCTION

The COVID-19 pandemic has been a disruptive force, interrupting the flows of daily life and normalcy. As a dueling public health crisis and economic crisis, the pandemic has exposed many cracks in society's structures, perpetuated by decades of neoliberal capitalism. As economies suffer grave downturns and mounting debt, the actions governments take to address these issues are crucial for the prosperity of the near future and to ensure a more equal society. The most common fiscal strategy to address economic crises in recent years has been policies of austerity, or short periods of economic stimulus followed by austerity policies. Both austerity and Keynesianism promote the idea that governments should run deficits in times of crisis—such as a recession—and run surpluses when the economy is thriving (Alesina et al., 2020; Quiggin, 2012; Russell, 2017). The issue in contention between the two approaches is how governments should fuel a sustainable economic recovery. Austerity policies generally aim to reduce deficit spending and decrease government debt by cutting spending, increasing taxes, or a mixture of both (Alesina et al., 2020). Proponents of austerity posit that its policies can be expansionary, encouraging economic growth by lowering consumer expectations of tax increases in the future and inspiring investment in the economy (Alesina, 2012). On the other hand, Keynesianism endorses considerable government spending through targeted welfare policies and programs to promote increased activity in the economy. (Quiggin, 2012; Russell, 2017). Keynesians also argue for increased control over the financial sector, as well as government intervention in the economy to ensure that economic growth can be sustained (Quiggin, 2012; Russell, 2017).

This paper will provide a historical analysis of both austerity and Keynesian stimulatory fiscal policy, examining the global economic outcomes of such policy applications in the past. It will then shift its focus to the Canadian context to explain how implementing austerity while the country is still in an economic downturn can produce negative consequences, and argue that Canada is in a fiscally stable position to handle the current level of debt and deficit

Published online
May 31, 2022

Citation

Newlove, J. (2022). Canadian government debt and deficit spending: Towards an efficient and equitable economic recovery to the COVID-19 pandemic. *CJUR*, 7(1), 18-21.

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spending. Finally, this paper will explain how austerity can have broader repercussions for society, potentially reinforcing or creating class and gendered inequities as well as damaging Canada's potential for a strong economic recovery. It will do so by highlighting examples of the consequences of harsh austerity measures implemented in other countries in the wake of the 2008 Financial Crisis. In sum, Keynesian stimulatory fiscal policy is ultimately the superior policy option to provide an efficient and equitable economic recovery. Such a recovery is essential to the rebounding of the Canadian economy, and with it, sufficient economic growth to reduce the government debt accumulated during this historic crisis.

A HISTORICAL ANALYSIS OF AUSTERITY

Proponents of austerity see government debt as a problem and seek to reduce it through policies that either cut public spending or raise taxes, or both (Quiggin, 2012). These policies are based on the 'Treasury view' of the Great Depression era, which posits that excessive public spending crowds out private investment or private consumption by increasing interest rates, and therefore state budgets should always be balanced (Quiggin, 2012).

Historically, the 'Treasury view' of austerity was utilized to address the Great Depression in most countries during the 1920s and 1930s. Governments of some of the largest economies at the time—the United States, the United Kingdom, and Japan—all enacted cuts to spending in an attempt to stimulate their economies. The results: unemployment soared, debt increased, the growth rate fell, and interest rates increased in these countries (Blyth, 2013a). These effects illustrate how, despite the implementation of austerity to stimulate growth by some of the most immense economic powers, economic woes on the contrary were only exacerbated. Due to these failures, austerity was replaced by Keynesianism as the dominant economic theory for the following 30 years.

Despite the relative success of Keynesian policies in creating economic growth and reducing unemployment, a series of economic crises and events beginning in the 1970s led governments to return to contractionary fiscal policies like austerity (Chick et al., 2016; Domitrovic, 2017; Quiggin, 2012). After the 2008 Financial Crisis in particular, governments responded with austerity measures to address the global economic crisis and growing government debt.

Many governments defended their enactment of austerity, utilizing recent literature on 'expansionary austerity.' This theory emphasizes the effect of expectations related to government finances on the economy. Supporters of expansionary austerity argue that when a government spends excessively and runs budget deficits, it creates an expectation of increased taxes in the future (Russell, 2017). As a result, aggregate demand is diminished, consumer spending drops, and private investment decreases due to weakened private sector confidence (Russell, 2017). On the other hand, implementation of austerity policies would produce an expectation of responsible financing of the economy, and thus consumer and investor confidence would increase domestically and internationally. Such confidence would prompt decreased interest rates, which would in turn further stimulate the economy (Russell, 2017).

The greatest challenge for proponents of expansionary austerity is proving that this concept successfully stimulates economic growth when the economy is in a downturn. A thorough analysis of statistically successful cases suggests that austerity is not conducive to economic growth and can actually hinder it. Advocates for expansionary austerity often point to Canada's policies implemented in response to the recession in the 1980s as an example of austerity succeeding in stimulating the economy. Recent analysis of Canadian economic growth in this period disputes the assertion that austerity measures were responsible for this growth. When the recession began, Canada was coming off a period of high growth, while significant trading partners were still expanding (Blyth, 2013b). Canada's continued economic growth in this period can be correlated with the economic boom in the United States, Canada's largest trading partner, as well as a large currency devaluation of the Canadian dollar (Blyth, 2013b). In other supposed cases of 'expansionary austerity' in this period, economic growth has been connected to similar fiscal and monetary determinants unrelated to austerity measures (Blyth, 2013b). These findings conclude that although there can be a correlation between austerity and economic growth, it does not imply causation as other economic and monetary measures can account for the trend.

THE AUSTERITY ALTERNATIVE: KEYNESIAN STIMULATORY FISCAL POLICY

This paper takes the position that the best strategy to address post-COVID debt is to stimulate the economy to produce economic growth. In response to the shortcomings of the economic responses to the Great Depression, Keynesianism became the dominant alternative to austerity (Quiggin, 2012). In advanced economies, Keynesian fiscal policy produced low unemployment rates, economic growth, and increasing living standards (Chick et al., 2016; Domitrovic, 2017; Quiggin, 2012). This theory posits that, in times of economic downturn, businesses do not have confidence that there will be large aggregate demand from consumers and as a result, investment decreases (Russell, 2017). Reduced investment by private business leads to a vicious cycle in which employment decreases, which in turn diminishes consumption; aggregate demand continues to fall, and business confidence becomes increasingly weaker (Russell, 2017). Keynesianism promotes government intervention within the economy to generate aggregate demand, thereby facilitating the investment of private businesses (Russell, 2017). Stimulative fiscal policy through increased government spending during economic downturns will produce this demand and increase business confidence, thereby generating further investment (Russell, 2017).

Government stimulus measures can be enacted in many ways, including through taxes, direct transfers, and spending. The literature on stimulus lends credence to the Keynesian position, with evidence suggesting that targeted stimulus measures increase economic output and raise gross-domestic-product (GDP) (Coenen et al., 2012). This effect is even more substantial when monetary policy supports the implementation of stimulus by keeping interest rates low (Coenen et al., 2012). Consumers tend to be myopic, ignoring the potential for future inflation or tax hikes (Coenen et al., 2012). Thus, they will generally consume more with their stimulus, increasing aggregate demand (Coenen et al., 2012; Parker et al., 2013). If Keynesian stimulatory fiscal policy is implemented and maintained for a long enough period of time, it

will generate sufficient economic growth to decrease debt in the long run without needing to resort to spending cuts or tax increases.

Canada's current fiscal position strengthens the argument for the government to implement stimulatory fiscal policies in response to the economic crisis of the COVID-19 pandemic. Critical to maintaining a solid fiscal standing is the state's ability and capacity to finance its debt. When government debt grows at a rate that surpasses the growth of the economy, public finances will not be sustainable in the long term (Wherry, 2020a). Markets and creditors to the government debt need to have confidence that the debt and money supply will not produce inflation by weakening the value of fixed-interest investment in state bonds and that government revenue will be able to cover the interest on the debt (Ingham, 2008). The key to maintaining the faith of financial markets and creditors is the debt-to-GDP ratio and the impact of interest rates in financing this debt. There is consensus on the international stage that debts are acceptable within certain limits. The European Union sets a standard maximum acceptable debt-to-GDP ratio at 60% (Ingham, 2008). Even critics of large-state spending posit that there is no consequential negative impact on economic growth in advanced economies until this ratio nears 90% (Reinhart & Rogoff, 2010). Taking into account the economic downturn and massive jump in spending by the government of Canada, the Parliamentary Budget Officer has projected that the debt-to-GDP ratio will only increase to approximately 48.3% (Office of the Parliamentary Budget Officer, 2020). This ratio puts Canada in the most favourable fiscal position of any G7 nation in relation to the federal net debt burden on the economy (Tencer, 2020). The other factor which indicates the ability of a government to deal with debt is the interest rate on the funds the government borrows. The current interest rate stands at a historic low of 0.25%, the lowest cost it has been for the government to borrow money in a century (Wherry, 2020b). As a result, economic growth is projected to overcome costs associated with interest in the future and avoid the factors which led to the Canadian fiscal crises in the 1990s (Wherry, 2020b). For these reasons, Canada is better positioned at this moment to finance the debt it is taking on to implement stimulatory fiscal policies than at any other point in the last 100 years.

AVOIDING THE PITFALLS OF AUSTERITY

Stimulatory fiscal policy helps to avoid many of the pitfalls of austerity, including negative economic consequences and increasing class and gendered inequality in society. In the Canadian context, austerity measures taken in the aftermath of the 2008 Financial Crisis unnecessarily undercut growth and the economy's ability to recover efficiently. Despite maintaining a reasonable debt-to-GDP ratio during the crisis, the government's implementation of austerity measures slowed economic growth and public investment (Dion & Dodge, 2016). Harsh austerity policies were enacted throughout Europe after the 2008 Financial Crisis, which resulted in economies contracting across the region. In fact, for the first time, the entire eurozone contracted in the fourth quarter of 2012 – economies shrank, net debt levels rose, and interest payments increased (Blyth, 2013a).

Austerity measures often result in an uneven recovery from economic crises. The imperative to cut spending can produce a 'wage moderation' effect, where the government reduces the

wages of civil servants (Russell, 2017). This downward pressure on wages can also affect the private sector's wages through direct government intervention or by producing a hostile environment for labour market conditions (Russell, 2017). The impacts of austerity have been theorized to have contributed to the stagnation of wages among the civil service and the working class, thus reinforcing income inequality in society (Russell, 2017). This inequality is also evidenced by the recovery of different classes from economic crises. In the United Kingdom, where severe austerity measures were imposed in the aftermath of the 2008 Financial Crisis, only the top 1% of households (as of 2017) have financially recovered and regained the level of income they had before the crisis (Vassilopoulou et al., 2019). These unequal outcomes between the working class and the more affluent in society can also impact economic growth in the wake of a crisis. When the working class, which makes up most of society, has stagnant or decreased income levels, it harms aggregate demand (Russell, 2017). In the Keynesian logic, without sufficient aggregate demand, there is little hope for economic growth, and thus the inequality of wages and speed of household financial recovery can drag down the speed of the economic recovery as a whole (Russell, 2017).

The pandemic has also exposed dramatic gendered inequalities in the workforce. The areas of the economy in which women make up a more significant percentage of the workforce—healthcare, social care, education, childcare, and the food service sector—have been disproportionately affected by the pandemic. Women in these 'care work' sectors of the economy are generally already overworked and underpaid, and the effects of the pandemic have only placed further strain on their existing working conditions (Thompson, 2020). The pandemic has also forced women into taking on more unpaid duties associated with social reproduction, consisting of the everyday tasks of maintaining and reproducing life (Bakker, 2007). With the closure of schools and other essential services, women are increasingly responsible for more care work for children and elderly relatives. This experience emphasizes the double burden women face – they work in underpaid, more flexible areas of the economy, and then complete unpaid domestic work at home (Thompson, 2020). The social infrastructure around care work, often called the fourth pillar of the welfare state, includes support for children and the elderly through preschools, daycare, nursing homes, and other support programs (Navarro, 2020). It is these social structures that alleviate the costs of social reproductive tasks to women and enables them to participate and fully integrate into the formalized workforce (Picchio, 2015).

To understand the potential detrimental implications of austerity, Greece stands out as a prime example. Greece arguably suffered the most severe impacts of the global economic crisis after 2008 and implemented harsh austerity measures in order to receive a fiscal rescue package. Following these cuts, which impacted many aspects of the welfare state, women's participation in the labour force dropped 14% (Vassilopoulou et al., 2019). This trend indicates that women are not only more disposable in the labour force, but also disproportionately bear the brunt of the impact when austerity measures cut funding to social infrastructure. Such an effect can be seen in the current crisis where, as a result of economic shutdowns affecting social infrastructures, women face the double burden of balancing professional work responsibilities and providing extra unpaid care work to children and the elderly. If Canada wants to avoid the labour market effects on women that

occurred in Greece after their policy response to the 2008 Financial Crisis, the Canadian government needs to avoid imposing stringent austerity measures and instead take a targeted approach towards funding programs that help women re-enter the workforce, thus facilitating a faster and stronger rebound for the Canadian economy.

From these findings, it is apparent that austerity can not only lead to unequal outcomes between women and men in society, but also have negative consequences for economies. There is substantial evidence that diversity of the workforce can create economic advantages through creativity and innovation, stimulating economic growth (Vassilopoulou et al., 2019). Recognizing this fact is crucial to enabling an efficient recovery from the economic crisis caused by the COVID-19 pandemic. It is evident that harsh austerity measures can produce unequal outcomes between men and women in the labour market. Such an impact not only promotes inequality, but it also hinders governments' ability to recover from economic crises efficiently.

CONCLUSION

In conclusion, austerity has been proven throughout history to produce adverse economic outcomes, as exemplified by its impact on economies following the Great Depression and after the 2008 Financial Crisis. Claims of 'expansionary austerity' are overblown by superficial analysis. Keynesian stimulatory fiscal policy is the most effective strategy for reducing government debt, as it avoids the pitfalls of austerity which often undercut growth and can cause economies to contract. Past applications of austerity have also perpetuated systems of inequality along the lines of class and gender. The COVID-19 pandemic is uniquely positioned to expose shortcomings in the current economic and welfare systems perpetuated by neoliberalism and austerity policies. These shortcomings have not only been exacerbated by the pandemic, but also risk hindering a more efficient and fair recovery, as exemplified by the stagnation of working-class income and the disproportional impact of cuts to social infrastructure on women. COVID-19 has exposed flaws in the economic systems which govern the daily lives of people around the world, and it is now up to governments to address these issues in their recovery efforts.

The author would like to thank Professor Jacqueline Best for inspiring this paper and her comments on the initial draft.

This article was submitted on March 18, 2021.

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Addressing the state of mental health in South Sudanese refugees across Uganda

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ABSTRACT The civil unrest in South Sudan has displaced masses of people, making it the world's third largest refugee population. Close to 40% of these refugees have fled to Uganda, where many occupy United Nations refugee settlements and attempt to build new lives for themselves. The traumatic and stressful experiences of living through war, violence, and human rights violations, escaping their home country, settling in a new environment, and a lack of specialized support services severely heighten the risk for these refugees to suffer from mental health problems and even develop mental disorders. Mental health problems and disorders amidst South Sudanese refugees in Uganda are indeed prevalent and a cause for concern, as suicide rates in refugee settlements continue to increase annually, and as poor mental health leads to increased domestic violence, substance use, and high student attrition rates that lower the quality of life for these refugees. This narrative review seeks to summarize the existing knowledge on the current state of mental health amidst South Sudanese refugees in Uganda by exploring the factors influencing mental health problems and disorders, in addition to the infrastructure and support available for mental health in refugee settlements. The review has found key causes of mental health problems to fall under the themes of financial and economic issues, war-related stressors, hardship and social instability within the refugee settlement, domestic problems, stressors specific to female refugees, as well as the vulnerability of young refugee populations. The available support for mental health is largely provided by international humanitarian organizations, which tend to focus on certain vulnerable groups, revealing a lack of mental health support and resources for the general refugee population. Using these findings, directions for future interventions and research are proposed.

INTRODUCTION

The 2013 civil war in South Sudan triggered one of the worst refugee emergencies seen in all of Africa and is the third largest in the world as of 2021, wherein over 2.2 million people were displaced (UNHCR, 2017b). South Sudanese citizens reported fleeing to neighbouring countries for a myriad of reasons, primarily the fear of physical and sexual violence, persecution, and forced recruitment of children for war (UNHCR, 2017b). Uganda, in particular, has experienced a rapid influx of South Sudanese refugees, and was projected to receive 20,000 more arrivals in 2020 (Adaku et al., 2016; UNHCR, 2017b; UNHCR, 2018a). There are a total of 1.5 million refugees in Uganda alone as of August 2021, with 61.6% of the population originating from South Sudan (UNHCR, 2021).

Brutal conflicts in South Sudan have claimed thousands of lives, while survivors live to have witnessed and undergone repeated human rights violations including rape, burning of villages, and torture (UNHCR, 2017b; UNHCR, 2018a). Even as they flee the country, they continue to experience stressful and traumatic encounters – the journey across the border subjects them to counts of violence, sexual assault, and exploitation by smugglers and armed groups who have detained escapees for ransom and even torture (UNHCR, 2018a). As a result of repeated abuse and mistreatment, many groups arrive in Uganda with malnourishment and deep psychological distress (UNHCR, 2018b). Their stress is often compounded as they settle into refugee camps, having to adjust to poor sanitation, overcrowding, and sexual violence (Finn Church Aid, 2019; Plan International, 2018; UNHCR, 2018b). The multitude of distressing events that South Sudanese refugees are typically exposed to, as well as having to battle the aftermath of trauma in a continually stressful environment void of robust services, severely increase their vulnerability to the development of mental health challenges.

Indeed, according to Adaku et al. (2016), there was a widespread mental health crisis amidst

Published online
May 31, 2022

Citation
Dev, D. K. (2022). Addressing the State of Mental Health in South Sudanese refugees across Uganda. *CJUR*, 7(1), 22-27.

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South Sudanese refugees in Uganda in dire need of mitigative action and support. The United Nations Children's Fund (UNICEF) has declared that most refugee children from South Sudan have experienced psychosocial distress (UNICEF, 2021). An assessment by the United Nations Refugee Agency (UNHCR) and partner organizations found that 19% of refugee households in northern Uganda reported at least one family member who suffered psychological distress (UNHCR, 2018b). Moreover, UNHCR found that the number of suicides and suicide attempts among South Sudanese refugees living in settlements in Uganda doubled in 2019 compared to the previous year (Nuri, 2020).

A high proportion of South Sudanese refugees in Uganda present severe signs of emotional distress and acute stress reactions (Mogga, 2017). Depression, anxiety, and post-traumatic stress disorder are among the most common mental disorders present amongst these people seeking refuge (Adaku et al., 2016; Finn Church Aid, 2019; Humanity & Inclusion Canada). A study conducted in Uganda found that 46% of South Sudanese refugees met the criteria for post-traumatic stress disorder while another South Sudanese study found that 50% of the sampled population met the criteria for depression (Karunakara et al., 2004; Roberts et al., 2009). Other common mental disorders among refugees in Uganda include bipolar disorders, alcohol and drug use disorders, and schizophrenia (Patel, 2007).

Individuals can, of course, experience symptoms that might be indicative of poor mental health at hugely varying degrees; while some may experience little to no mental health challenges, others can experience symptoms severely. Indeed, reports have shown that upon arrival at refugee settlements, some groups, especially children (who are vulnerable at their developmental age), can face psychological and somatic manifestations of trauma responses including insomnia, regressive behaviours, social withdrawal, and self-destructive outbursts (World Vision, 2020). When symptoms are left untreated or unsupported for long periods of time — especially when aggravated by the existing challenges that South Sudanese refugees face, such as poor working conditions, poverty, and documented hostility from host communities (Adaku et al., 2016; UNHCR, 2018b) — detrimental impact to the individual's wellbeing becomes increasingly likely. Indeed, studies have shown proof of decline in cognitive functions such as attention, processing speed, and executive function in individuals with psychiatric symptoms (Lam et al., 2014; Hasselbalch et al., 2015; Trivedi, 2006). This may be a contributory factor to the high rate of absenteeism and dropouts commonly seen from schools in Uganda's refugee camps (Finn Church Aid, 2019; Ministry of Education and Sports, 2018). Furthermore, individuals may turn to negative coping mechanisms such as alcohol use, substance use, and self-injury, which, if left unsupported, could result in exacerbation of mental health issues through manifestations like substance use disorders and suicidal behaviours (Center for Substance Abuse Treatment, 2014; Finn Church Aid, 2019; Woodward et al., 2020).

We recognize that stressful or traumatic events affect individuals to hugely varying degrees, wherein individuals can present an array of psychological responses subjective to myriad factors such as their psychological traits, developmental processes, and severity of trauma. However, it is crucial to address possible dire outcomes in which mental health problems in some individuals can significantly impact wellbeing as a result of maladaptive

behaviour, suicidal thoughts, physiological dysfunction, and more (Adaku et al., 2016; Gross et al., 2019). We must acknowledge the urgency of the situation in order to tackle it before such possible outcomes become a reality for many more South Sudanese refugees. To do so, we must address the above reports which highlight the mental health challenges experienced by South Sudanese children, the impact this may have on the completion of their primary or secondary education (Lam et al., 2014; Hasselbalch et al., 2015; Trivedi, 2006), the knock-on effect this may have on access to further education and training, the labour market, and increased economic stability (Ganasen et al., 2007; Onyut et al., 2009). Indeed, at least 80% of refugees in Uganda already live below the international poverty line of US \$1.90 per day, a financial strain that only further impacts the mental health of individuals, their peers, and family members, all while perpetuating vicious cycles of poverty and poor health (Ganasen et al., 2007; UNHCR, 2019). For example, violent tendencies can present themselves in certain individuals struggling with psychological symptoms and disorders (Link et al., 2015; Webermann & Brand, 2017), causing severe anxiety and fear in the peers who interact with them and ultimately leading to the development of anxiety and panic disorders in some (UNHCR, 2019). Moreover, reports have shown that the domestic and financial responsibilities of young children significantly increase when family members are experiencing challenges due to their mental health problems (Plan International, 2018). The burden that these children have to handle at such a young age can present itself as a major stressor leading to serious stress-related mental disorders (MSF, 2019; Plan International, 2018).

In an attempt to raise awareness about the gaps in mental health support and interventions across refugee settlements in Uganda, this review summarizes and evaluates the existing knowledge of the factors influencing mental health issues amidst South Sudanese refugees, as well as the existing infrastructure and resources available to support mental health in refugee settlements. Finally, the review discusses future directions for mental health interventions in refugee settlements based on the obtained findings. This article is presented as a narrative review because there is insufficient research in this field to complete a systematic review or meta-analysis.

METHODS

The literature search was completed in multiple phases across various databases. Google Scholar, Pubmed, Web of Science and MEDLine were first searched using various combinations of keywords such as "South Sudanese refugees", "Uganda", "mental health", "psychosocial support", and "mental disorder". Relevant articles that focused on any combination of these keywords were included. Articles dated before the year 2000 were excluded from the search.

From these initial results, more specific searches were conducted using keywords including the names of the refugee settlements, such as "Bidi Bidi", "Imvepi", and "Palorinya", as well as the names of humanitarian organizations, such as "UNHCR", "Transcultural Psychosocial Organization", "Médecins Sans Frontières" and "Finn Church Aid". Due to the lack of published research in journals specifying the work of these organizations, searches were conducted on Google to identify strategic plans,

situation reports, and evaluation reports issued from these humanitarian organizations.

We present this article as a narrative review because little research exists in this field and there is insufficient research content to complete a systematic review or meta-analysis.

LITERATURE REVIEW

Table 1 Factors influencing mental health problems amidst South Sudanese refugees in Uganda

Factor	Specific stressor
Financial and Economic	Affordability of sanitation and menstrual supplies Child labour Lack of access to education Poverty Unemployment
Within the Refugee Settlement	Hostility from some members of the host community Insufficient health services Lack of sanitation facilities Poor living conditions Stigmatization (constant identification as refugees)
War-Related	Trauma from escaping war zones Trauma from living in war zones Trauma from sexual and physical violence
Domestic	Alcoholic or drug-addicted parents and/or spouses Child labour Domestic violence Hostile home environment Lack of male head in family (fighting or targeted in war, death) Parents preventing children from attending school Sexual violence and assault
Girls and Women	Early marriage Household expectations and domestic workload Menstrual management – stigma of menstruation, lack of access to information and sanitation facilities Premature pregnancy Sexual violence by family and/or community members
Children and Youth	Alcoholism and drug abuse Group and peer influence Premature pregnancy School dropouts Unaccompanied minors living alone

Factors Influencing Mental Health Problems

The causes of mental health problems amidst South Sudanese refugees in Uganda are widespread and multifaceted. Stressors that contribute to poor mental health have been categorized and summarized in Table 1.

According to Nuri (2020), key factors contributing to a greater rate of mental illnesses and suicide include incidents of sexual and gender-based violence (SGBV), poverty, and traumatic events pre- and post-escape from home countries.

The Bidi Bidi refugee settlement, which is the largest refugee settlement in Uganda and home to more than 99% of South Sudanese refugees, had 570 documented cases of SGBV in 2017 alone (UNHCR, 2017a). Girls and women are assaulted not only within the community, in the streets, or on their way to school, but also within their families in the form of early and forced marriage

(Finn Church Aid, 2019; Plan International 2018; UNHCR, 2017a). Forced marriage is a way to sustain basic needs for shelter, food, and security (Finn Church Aid, 2019), but it puts the health, education, and sexual protection of many girls at risk (Finn Church Aid, 2019; Mogga, 2017; Plan International, 2018). In a report by Plan International, young female refugees in Uganda identified access to education as a crucial aspect of their lives, as they believed education would protect their future by granting them independence through job security and financial stability as well as by preventing forced marriages (2018). However, female refugees report having excessive domestic workload such as caring for younger siblings, performing general household chores, and attempting to earn money, which result in an inability to focus on their education (Plan International, 2018). As a result, many young female refugees are unable to reap the protective benefits of education, as can be observed in a disproportionate ratio of male to female refugees (2:1) accessing secondary education in Uganda (Ministry of Education and Sports, 2018), and instead become increasingly prone to forced marriage and dependence on male figures. This can increase the prevalence of young females staying in exploitative and abusive relationships, which can be detrimental to their mental wellbeing (Finn Church Aid 2019; UNHCR, 2017a).

Meanwhile, poverty has been shown to have a statistically significant positive relationship with the prevalence of mental disorders, as economic inequity not only influences the provision of mental health services but also negatively impacts mental health (Ganaseen et al., 2007). The extreme poverty in which refugees live contributes to the rise of stressors that can aggravate mental health conditions, such as food insecurity, inadequate healthcare services, and poor living conditions within the settlements (Adaku et al., 2016; Finn Church Aid, 2019). Moreover, this leads to adverse consequences for children and youth who are expected to generate income for the family, forcing them into child labour, which is mentally, physically, and socially harmful to them (Mogga, 2017; Plan International, 2018).

Research has shown that most mental disorders can begin between age 12 and 24, and more than 75% of mental health problems occur before age 25 (Kessler et al., 2005; Kessler et al., 2007; Okello et al., 2014). The diathesis-stress model as a framework in psychopathology has established that mental health burdens in childhood — in this case, traumatic experiences from living in and escaping war zones — can manifest themselves as both diatheses (underlying vulnerability) and stressors that lead to the development of negative coping behaviours and mental health issues (Broerman, 2018; Colodro-Conde et al., 2018; McKeever et al., 2003). The negative coping behaviours individually may also exacerbate mental health issues and contribute to the etiology of mental disorders in adulthood (Adaku et al., 2016; Finn Church Aid, 2019; Woodward et al., 2020).

Existing Infrastructure and Support for Mental Health

The Ugandan government has implemented progressive policies to support refugees in settlements, such as allowing them to live, farm, and work (UNDP, 2017). However, measures to improve psychological support and mental health within refugee populations have not been taken into account. The foundation of the existing infrastructure and support for mental health is largely made up of resources from international organizations and

agencies.

UNHCR formed a mental health working group in the Bidi Bidi refugee settlement in 2017, where 196 cases were registered and assessed (UNHCR, 2017a). Their mental health support has primarily been focused on unaccompanied refugee children and has been realized by working with partner non-profit organizations to provide community-based child protection. To do this, committees have been established to monitor abuse and conduct training sessions on positive parenting, child abuse, children's rights, and recognizing symptoms of trauma for foster families (UNHCR, 2019; UNHCR, 2020). The United Nations Entity for Gender Equality and the Empowerment of Women, also known as UN Women, has provided psychosocial support to female refugees across northern Uganda since 2013 (UNHCR, 2017a). The focus of UN Women is to offer support to victims of sexual and gender-based violence (SGBV) and sexual abuse through medical aid and education. Finn Church Aid (FCA) work to provide humanitarian assistance in the Bidi Bidi and Parolinya settlements; while they typically focus on education by creating permanent classroom structures and leading the education curriculum in the settlements, FCA have developed counselling services within the schools to support the mental health of the students (Finn Church Aid, 2018; Finn Church Aid, 2019). The Transcultural Psychosocial Organization (TPO) has provided an impressive amount of psychosocial support to the refugees at the Bidi Bidi refugee settlement; they have established psychological support and therapeutic interventions such as cognitive behavioural therapy for survivors of SGBV, which include comprehensive pre- and post-program assessments and sessions (Mogga, 2017). They have additionally provided education to survivors about mental health and illnesses, increasing their mental health literacy (Mogga, 2017). Through collaboration with UN Women, they have implemented advanced psychosocial support interventions for SGBV survivors (Nuri, 2020). TPO is one of the few organizations that have established programs educating the refugee population on suicide prevention, coping behaviours, and eliminating stigma associated with mental health (Nuri, 2020). They have also trained community healthcare providers on mental health care and deployed counsellors within the communities (Mogga, 2017; Nuri, 2020). TPO has additionally focused on providing services to refugee children centered around trauma healing and has worked with World Vision to implement specialized interventions for children struggling with high levels of trauma (Mogga, 2017; World Vision, 2020). According to Mogga (2017), in order to promote positive mental wellbeing, they have also established life skills development programs for youth and structured activities for children in child-friendly spaces. Médecins Sans Frontières (MSF) has taken into account mental health care when establishing their humanitarian healthcare programs, having started a SGBV and mental health clinic in the Bidi Bidi settlement with a trained team of psychologists, psychiatric nurses, psychiatric clinical officers, social workers, community health educators, midwives, and interpreters that largely provide support for post-traumatic stress disorder and depression (Ohanesian, 2019). MSF also opened a SGBV clinic in the Imvepi settlement in 2017 that continues to provide extensive psychological care services to SGBV survivors (MSF, 2019). Overall, MSF has provided 8600 individual mental health consultations across Uganda in 2017 alone (MSF, 2019). The Humanity & Inclusion (HI) organization works in the Omugo settlement, providing psychological first aid training to frontline

aid workers and integrating psychiatric services in the local hospital (Humanity & Inclusion Canada). They have deployed teams of psychologists and social workers who provide comprehensive, long-term psychological care to patients (Humanity & Inclusion Canada). The Center for Victims of Torture (CVT) works to support victims of trauma and torture in the Bidi Bidi settlement, providing rehabilitative care through long-term mental health care programs led by local counselling professionals as well as psychological first aid to refugees in need of immediate care (The Center for Victims of Torture).

The UNHCR has estimated that US\$927 million is required to address the basic needs (e.g., water, sanitation, food, health care, shelter) of the refugees in Uganda (Nuri, 2020). Unfortunately, the UNHCR and partners working on the refugee response have only amassed 40% of this amount, most of which has been contributed by donors in the international community (Nuri, 2020; UNHCR, 2019). These funds have reached just 29% of the South Sudanese refugees in need of these mental health services, and the organizations supporting mental health interventions continue to appeal to the generosity of donors to obtain funding (Nuri, 2020).

DISCUSSION

Reviewing the existing mental health infrastructure and support in place for South Sudanese refugees in Uganda, there is evidently limited mental health and psychosocial support available at an institutionalized level, and response efforts largely stem from international humanitarian organization and agency initiatives. Moreover, most interventions concentrate on providing support to victims of SGBV, with a minority focusing on other vulnerable groups such as unaccompanied children or young refugees suffering from high trauma levels. While the literature clearly indicates that SGBV and trauma are key contributors to mental health problems that disproportionately affect women and children—necessitating the delivery of specialized mental health services for these groups—this review has identified several other factors that are influencing mental health problems. Significantly, these factors are not exclusive to vulnerable groups in the community, but instead are more broadly applicable to most if not all individuals in Uganda's refugee settlements. Examples include financial stressors such as poverty and lack of access to employment opportunities, trauma from displacement (fleeing war and human rights violations in South Sudan), as well as stressors from living in a settlement, such as hostility from members of the host community and lack of access to basic provisions (Table 1). These stressors are relevant to the refugee community at large, making the general refugee population (and not only the addressed vulnerable groups) highly susceptible to mental health issues. Encountering adversity regularly debilitates their mental state, causing them to become increasingly vulnerable to events that may trigger mental disorders and problems. Despite the widespread presence of the general stressors in the refugee settlements, most current mental health interventions do not endeavor to address them, hence overlooking a significant proportion of individuals who may need support, but do not fall under a specialized group (e.g., victims of SGBV, unaccompanied minor, victims of torture). This necessitates the implementation of mental health interventions that are targeted at the general refugee population. One could argue that these stressors are social determinants of mental health issues that should be tackled by the

government and institutional policies to improve societal outcomes, yet the impact of these stressors on the mental health of the refugee community can be alleviated through interventions that center on empowering individuals to manage their mental state amidst generally stressful events and hardship.

A recommendation for such a form of mental health intervention is one that focuses on mental health literacy. Mental health literacy is defined as the knowledge and beliefs about mental disorders which aid their recognition, management, or prevention (Jorm et al., 1997). By introducing mental health literacy programs to educate refugees about mental health problems and address mental health stigma, they can be better equipped to cope with the aforementioned stressors (that would otherwise compromise their mental wellbeing) through generalized methods. For example, programs can teach individuals strategies to moderate the impact of stress on mental wellbeing, or ways to alter their behavior and thoughts when facing negative events, which would empower them to manage their mental state when dealing with stressors. Additionally, mental health literacy can help refugees struggling with poor mental health to make informed decisions about seeking help and treatment. This is especially beneficial as refugees would be able to undergo early intervention to prevent the exacerbation of their mental health problems and even impede the onset of psychiatric disorders from potentially triggering events in the future. Existing literature suggests that mental health literacy is associated with increased use of positive coping methods, more positive attitudes toward help-seeking, and fewer stigmatizing beliefs and attitudes toward mental health issues, which eradicate barriers to tackling mental health problems (Cheng et al., 2018; Jung et al., 2016; Svensson & Hansson, 2016; Venkataraman et al., 2019). Implementing such a generalized intervention that serves the refugee community as a whole counteracts the caveat of existing resources (wherein they are only tailored to specific groups in the community), hence meeting the need for mental health support for a substantial number of individuals who would otherwise be neglected.

We recognize that there is a paucity of literature and information about the topics that have been covered in this review. Not enough comprehensive needs and resource assessments have been conducted across all refugee settlements in Uganda to provide a thorough representation of the causes of mental health problems amidst the refugee populations. Furthermore, most reported mental health interventions by non-profit and humanitarian organizations have been located in the Bidi Bidi refugee settlement, since it is the largest settlement in Uganda. Local efforts to improve mental health outcomes in the communities, and concerted efforts to understand local conceptions of mental health, may have been neglected in the existing literature and must be centered in future interventions. Nevertheless, this review summarizes important information to contribute to the understanding of the state of mental health and available support for South Sudanese refugees in Uganda.

Our review will inspire further research in South Sudanese refugee settlements in order to better understand the level of need as well as existing gaps with regards to mental health challenges and available resources. Additionally, such research can inform the effectiveness and validation of mental health interventions developed to improve overall mental health outcomes in refugee populations.

The author would like to thank Eli Wyatt for his mentorship, encouragement and useful critiques of this review, and Simbi Foundation for supporting their research efforts.

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Testing antimicrobial effects of tea tree oil using *S. cerevisiae* and bread mold

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ABSTRACT Tea tree oil (TTO) is a naturally-occurring chemical extracted from the leaves of the narrow-leaved paperbark tree. It is well known as an antiseptic, but its potential as a natural household cleaning agent has not been thoroughly examined. We were interested in examining the anti-fungal properties of TTO, especially on common bread mold, spores of which are common to households. This study used fresh-baked white bread as media to observe the effects of TTO at 0.06% and 0.24% concentrations on mold spore formation and 0.25% TTO on yeast fermentation. It was concluded that TTO can inhibit mold growth at 0.06% concentration but did not reduce ($p=0.07$) yeast CO₂ production even at 0.25% concentration. The data highlights the efficacy of TTO against household mold and, based on our yeast results, is potentially non-toxic at low concentrations. More studies are required with a variety of mold species and concentrations of TTO to better understand its use as a cleaning agent.

INTRODUCTION

A Tea Tree Oil (TTO) is extracted from the tree *Melaleuca alternifolia*, found in Australia (Hammer et al., 2006). When used topically, TTO has exhibited antimicrobial and antifungal effects and is an antiseptic to treat wounds (Low et al., 2017). The presence of household mold exposure has previously been linked to various respiratory issues, such as asthma in children (Zhang et al., 2021). Thus, there is a need for antifungals that are safe to use in household settings, and TTO is a natural alternative to harsher chemical agents that are currently being used. Moreover, the use of tea tree oil as a film coating over computer keyboards has been shown to significantly decrease bacterial loads in hospital settings (Melegari et al., 2021). This indicates potential unexplored applications of TTO, especially as an eco-friendly alternative to chemical cleaners.

Most common household microbes are mold that grows under high humidity and temperature (Vagelas et al., 2011) and commonly belong to the genera *Aspergillus*, *Mucor*, *Fusarium*, and *Rhizopus* (Garcia & Copetti, 2019). TTO has previously been tested as an effective antifungal that can completely inhibit *A. fumigatus* indoors, in both liquid and vapour forms via direct contact (Rogawansamy et al., 2015). However, its properties as a potential household cleaning oil have not been thoroughly evaluated.

TTO is made up of multiple phytochemicals. The most active component is terpinen-4-ol, which causes the membrane of the target organisms to become more permeable (Rogawansamy et al., 2015). This causes irreversible damage to the bacterial cell membranes, resulting in the loss of essential cell constituents and eventually death (Shi et al., 2018). The minimum inhibitory concentration of TTO against a wide range of fungi was found to be 0.004% to 0.25% (Hammer et al., 2002).

Due to COVID-19 restrictions on lab activities, we devised a method to test out the efficacy of TTO on bread mold and yeast under controlled conditions in situ. White bread was used as a growth media for growing mold and testing the inhibitory properties of varying concentrations of TTO in four separate experiments. The efficacies of the TTO concentrations were further evaluated on gas production by *Saccharomyces cerevisiae*, as a measure of toxicity.

Published online
May 31, 2022

Citation

Patel, J.; Kaur, L.; Shastri, P. (2022).
Testing antimicrobial effects of tea tree
oil using *S. cerevisiae* and bread mold.
CJUR, 7(1), 28-31.

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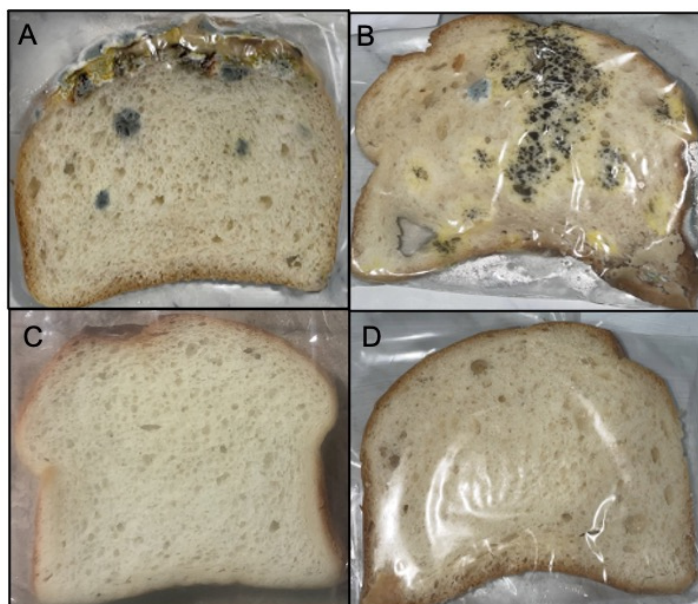


Figure 1 White bread exposed to different treatments after 7 days when placed in dark, humid environment at $\sim 25^{\circ}\text{C}$. A = no treatment; B = water; C = 0.06% TTO; D = 0.24% TTO.

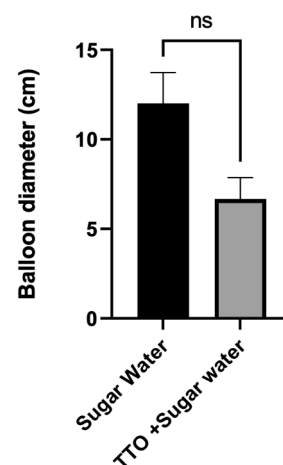


Figure 2 Bars represent the average balloon diameter \pm standard error mean (SEM). Amount of gas produced by *Saccharomyces cerevisiae* (yeast), captured in the balloon, was unaffected by 0.25% TTO ($p=0.07$) as determined by unpaired Student's t-test. The data is the average of three independent replicates. The diameter of the balloon for all associated negative controls (water + sugar, water + yeast, water + sugar + 0.25% TTO, water + yeast + 0.25% TTO) was 0 cm.

Table 1 Average number of CFU on white bread when exposed to 0.06% and 0.24% TTO after 7 days under dark, humid conditions at $\sim 25^{\circ}\text{C}$. Colony Forming Units (CFU) are reported as an average \pm standard error mean (SEM) of 4 replicates. TTO = Tea Tree Oil; NG = no growth.

Treatment	Average number of CFU \pm SEM
Bread alone	12 \pm 0.6
Bread + water	17 \pm 0.8
0.06% TTO	NG
0.24% TTO	NG

METHODS

TTO Effect on Mold Growth

The effect of TTO on the growth and spread of mold spores was analyzed. In-store (Fortinos) baked white bread was used as growth media and placed under conditions that will promote the growth of common bread mold, further explained below.

The number of Colony Forming Units (CFU) was compared in the presence of TTO.

TTO (Holist brand, 50mL bottle) media was diluted to 0.06% and 0.24% (v/v) and dissolved using water to obtain a total volume of 10 mL. Ziplock bags were labeled, and the bread was cut into approximately 8 cm \times 5 cm \times 1.25 cm slices and placed in each bag. A 100 mL refillable plastic spray bottle was used to spray 10 mL of each TTO concentration onto separate bread slices inside the Ziplock bags, which were then sealed. Two negative controls were prepared by spraying 10mL of water onto one slice of bread, while another slice was placed in a bag without any liquids. The positive control was the bread sprayed with 0.24% TTO, as this was previously shown to be the highest concentration that inhibits mold (Hammer et al., 2002). All samples were sealed in Ziplock bags and placed in a dark room at $\sim 25^{\circ}\text{C}$ which was

maintained by monitoring house thermostats. The growth of mold was observed every day for 7 days.

TTO Effect on Yeast Growth

The effect of 0.25% TTO as a toxicant was tested on *S. cerevisiae*. A solution of yeast (Fleischmann's quick-rise instant yeast) + sucrose (table sugar) was prepared to allow fermentation to occur, and the amount of gas produced was measured. In the presence of 0.25% TTO, the gas production was compared with yeast + sugar solution without TTO to see the effects of TTO on yeasts' ability to produce measurable gas. More details are described below.

The yeast solutions were prepared using 100mL of water and 2% (w/v) of yeast and 2% (w/v) of sugar. The test samples were placed in bottles and were prepared by adding 5 drops of TTO to make 0.25% TTO. This method of dilution was found to be simpler, as 20 drops were measured to equal 1mL, therefore 5 drops were used to make 0.25% (v/v) TTO in 100mL of water. The controls were set up alongside the test samples with the same 100mL volume. Negative controls were bottles with water + sugar, water + yeast, water + sugar + TTO, and water + yeast + TTO. The positive control was water + sugar + yeast. All samples were then mixed, and the bottle opening was covered with a balloon to collect any gas produced from the mixture. The bottles were placed in a hot water bath for 40 minutes

to maintain an average temperature of 45°C. The diameters of the balloon after 40 minutes were recorded to analyze the amount of gas produced in the fermentation process.

Statistical Analysis

The effect of TTO concentration on gas production by *S. cerevisiae*, grown in sugar water, was analyzed using an unpaired Student's t-test with GraphPad Prism 9.0.

RESULTS

Mold CFU on bread shown in Figure 1 were counted following 7 days of exposure to various treatments, listed in Table 1. TTO concentrations affected the amount of mold growth on white bread. Average CFU of bread mold dropped from 12 ± 0.6 and 17 ± 0.8 CFU on the negative controls to 0 CFU on bread treated with 0.06% and 0.24% TTO. Thus, tea tree oil inhibited the growth of mold.

To further verify the toxicity effect of TTO on eukaryotic cells, we hypothesized that 0.25% TTO will inhibit yeast growth which leads to decreased CO₂ production. The results of the experiment are shown in Figure 2. It was expected that as yeast used sugar as an energy source for fermentation, the balloons would increase in diameter from CO₂ production. The first column representing the positive control of the experiment showed that the diameter of the balloon increased by an average of 12 ± 3 cm, after approximately 40 minutes. The second column represents the results with the addition of 0.25% TTO, where the diameter of the balloon increased by an average of 6.67 ± 2.1 cm. Due to a small sample size (n=3), an unpaired Student's t-test was performed. Since $p=0.07$, the addition of 0.25% TTO did not significantly affect sugar utilization of *S. cerevisiae*, indicating TTO at 0.25% concentration is potentially non-toxic. The negative control bottles showed no gas production.

DISCUSSION

Tea Tree Oil is a potential natural alternative to household chemical cleaners that is still under-studied. This study tested the efficacy of TTO in reducing mold growth by using bread as a growth medium, and by evaluating its toxicity to eukaryotic cells by measuring the reduction of CO₂ production by *S. cerevisiae*.

In the first experiment, the bread sprayed with water had more mold colonies than just bread that was not sprayed. This was expected because previous research has shown that higher moisture content or humidity offers better growth conditions for mold (Axel et al., 2017). It has also been previously shown that TTO can inhibit grey mold *Botrytis cinerea* that forms on fruit, but the mechanism of how the growth is affected is still unclear (Shao et al., 2013). We found that 0.06% and 0.24% TTO concentrations inhibit visible colony formation at room temperature in humid and dark environments. Our results are similar to previously published data at these minimum inhibitory concentrations (MIC) against fungi (Hammer et al., 2002).

In the second experiment, it was found that 0.25% TTO did not significantly inhibit yeast growth as gas production in the

treatment sample was not significantly different to those observed in the negative controls, suggesting a lack of toxicity at this concentration. Although, TTO has previously been shown to have antifungal effects against yeast such as *Candida* species (D'Auria et al., 2001). Given that the MIC values we used in the study were based on filamentous fungi and dermatophytes but not baker's yeast *S. cerevisiae* (Hammer et al., 2002), further studies evaluating the toxicity effects of TTO using *S. cerevisiae* would help determine the safety limits of TTO.

Methods described in the study were used due to COVID-19 restrictions on in-person lab attendance, leading to a more 'citizen-science' approach. Thus, these results would need to be re-examined in a controlled laboratory setting to determine the effect of TTO on microbes.

There were some limitations in the experiment. 1) pH of media was not measured; it could not be ruled out as a factor affecting the growth of mold or yeast. 2) There could be volume inaccuracies between our replicates since our measuring techniques were not as precise as they would have been if we used calibrated pipettes. 3) We did not have access to various mold species, which would help establish the range of TTO concentrations required to inhibit them. In addition, future experiments can be performed to test the efficacy of TTO concentrations on surfaces using RODAC plate or the swab method. Another avenue of testing is to evaluate the microbial load with a microbial air sampler before and after spraying TTO.

CONCLUSIONS

In conclusion, it was found that TTO can inhibit visible common bread mold growth at the lowest concentration of 0.06%, but does not significantly reduce yeast viability even at 0.25%. This shows that tea tree oil can potentially be used as an antifungal in home settings, especially because it is a natural oil, and because it is efficient at low concentrations.

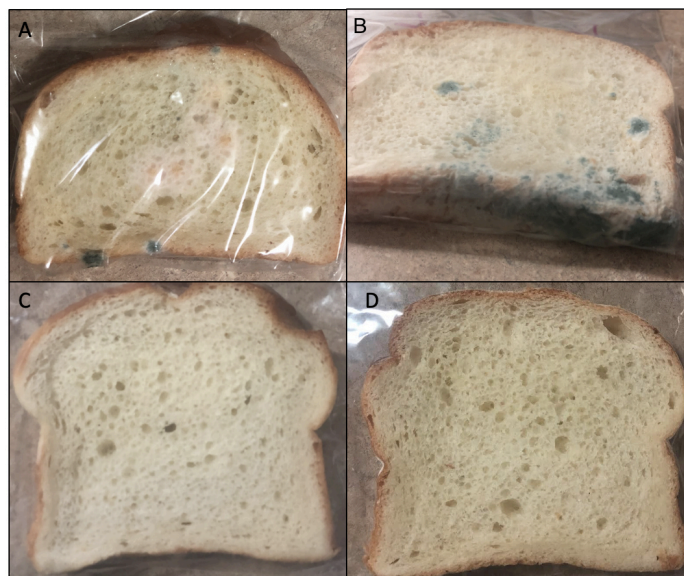
This research article is derived from the Winter 2021 semester course BI206 (Microbiology Project 2) taught by Dr. Padmaja Shastri in the Department of Applied Biological and Environmental Sciences at Centennial College, Toronto, Canada.

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Supplementary Figure 1 White bread from an additional trial exposed to different treatments after 7 days when placed in a dark, humid environment at ~25°C. A = no treatment; B = water; C = 0.06% TTO; D = 0.24% TTO.

Dataset for **Figure 2**. Diameter of balloons placed on the lip of the positive control and 0.25% TTO concentration bottles placed in a 45°C-water bath for 45 minutes.

Bottle contents	Balloon diameter (cm)				Average	STDEV
	Trial 1		Trial 2			
	Lovleen	Jenisha	Lovleen			
Positive control (100 mL water, 2g sugar, 2g yeast)	15	9	12	12	3	
100 mL water, 2g sugar, 2g yeast, 0.25% TTO	9	6	5	6.6667	2.0817	

Gadolinium contrast agents in magnetic resonance imaging (MRI)

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ABSTRACT Magnetic Resonance Imaging (MRI) is one of the most powerful clinical diagnostic tools. Based on chemical principles discovered in the 1940s, MRI uses magnetic fields to excite bulk water protons throughout the body, creating an image from their responses. Although useful for the diagnosis of a variety of diseases and conditions, a lack of image clarity can result in incorrect or missed diagnoses. Due to the inherent challenges with MRI, gadolinium-based contrast agents (GBCAs) are used to modulate the response of the bulk water protons to the external magnetic fields, subsequently increasing the image contrast. Here, we discuss GBCAs and their role in overcoming the challenges with magnetic resonance (MR) image clarity.

INTRODUCTION

Magnetic Resonance Imaging (MRI) is one of the most vital technologies for diagnostic medical procedures, as well as disease detection and monitoring progression. Although there are limitations with cost, instrument size, and acquisition time, MRI remains one of the most effective non-invasive diagnostic methods. However, the clarity of magnetic resonance (MR) images may be impaired due to the lack of contrast between tissues, which can result in missed diagnoses (Leung, 2012). Image contrast is particularly important for the detection of certain cancers, notably breast cancer, in which tumors can be completely invisible to imaging (Wallace et al., 2005). This can be overcome through the use of paramagnetic gadolinium(III)-based contrast agents (GBCAs) to improve image clarity, diagnosis effectiveness, and patient care (Lin & Brown, 2007; Wahsner et al., 2019; Xiao et al., 2016). Approximately 40% of all MRI scans and 60% of central nervous system (CNS) MRI scans are administered with GBCAs, amounting to nearly 40 million total GBCA administrations worldwide annually (Runge, 2017). Two major limitations with GBCAs are their inherent toxicity and their potential to remain in the patient after the scan. From a clinician's perspective, understanding the function and limitations of these drugs is crucial for their proper use in hospital settings (Wahsner et al., 2019).

This review will begin by outlining the mechanisms of MRI and compare contrasted vs non-contrasted MR images. Then, an analysis of ligand design and the mechanisms of action of GBCAs will show how they increase the brightness of the images. Finally, this review will conclude with a discussion of the limitations of GBCAs and directions for future research.

FUNCTIONS OF MAGNETIC RESONANCE IMAGING

Since the experimental description of nuclear magnetic resonance (NMR) in 1946 by Bloch and Purcell, a Nobel Prize-winning discovery, the field of radiology has seen widespread advancement (Bloch, 1946; Leung, 2012). The first clinical use of magnetic resonance for diagnostic imaging was in the early 1980s and has since been used in nearly all fields of medicine (Hawkes et al., 1980; Smith et al., 1981).

Drawing from NMR technology, MRI makes use of the unique characteristics of hydrogen atoms to create images of internal tissues. Since humans are composed of approximately 70% water, there are many hydrogen atoms (each containing both a proton and an electron)

Published online
May 31, 2022

Citation
Johnston, L. P. A. (2022). Gadolinium Contrast Agents in Magnetic Resonance Imaging (MRI). *CJUR*, 7(1), 32-37.

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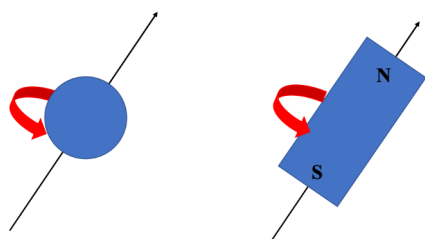


Figure 1 Water proton spin and bar magnet representation. Notice that the left spherical representation is a mathematical approximation of spin. Though this approximation allows for theoretical conclusions, other factors, such as angular momentum, are at play. More accurately, a proton can be visualized as a bar magnet with north and south poles. Although a water proton will not be labelled as such, we can imagine that the spin creates a magnetic moment which has polarity. This polarity is what causes the specific alignment of these protons when an external magnetic field is applied, releasing energy upon relaxation. This released energy can be detected and visualized as magnetic resonance images.

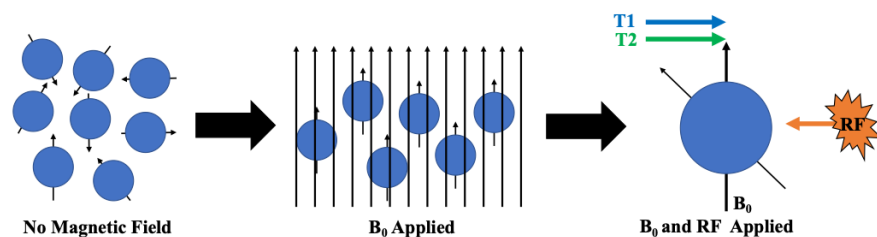


Figure 2 Bulk water protons aligning with the B_0 and RF magnetic fields. When no magnetic field is applied (e.g., normal human body), the hydrogen spins are all in different directions. After the initial B_0 magnetic field is applied, some of the hydrogen nuclei spins will line up with the direction of the applied magnetic field (about 4/1,000,000). During the pulsating RF magnetic field, the hydrogen nuclei's spin gets bumped off the B_0 axis (like tipping a spinning top), and subsequently returns via either T1 or T2 relaxation pathway.

present throughout nearly all tissues (Berger, 2002). The hydrogen protons have spin, which can be imagined as a vector with polarity, and will align itself parallel or anti-parallel to the magnetic field (Figure 1). Although there are no positive or negative ends of this imaginary vector, this intrinsic proton spin results in a magnetic moment, which causes a specific alignment of the bulk water protons when applied with a magnetic field (Huk & Gademann, 1984; Grover et al., 2015). MR images are created through slight polarization of proton spins by an external magnetic field, resulting in signals that can be picked up by the detection device (Lauterbur, 1973).

During an MRI scan, the patient is placed in a superconducting magnet which applies a strong magnetic field throughout the body part being analyzed. This applied magnetic field, B_0 , orients some of the hydrogen atoms in the direction parallel to it, which places them in a low energy state (Figure 2) (Grover et al., 2015; Leung, 2012). Within the static magnetic field of B_0 , the nuclei can be further excited upon the presence of pulsing radiofrequency (RF) waves, causing a secondary magnetic field. The RF is applied in bursts, and the absorption of this energy will bump the central axis of the hydrogen atom out of alignment with B_0 , like tipping over a spinning top (Figure 2) (Huk & Gademann, 1984). Only a few protons line up in a low energy state with the magnetic field (approximately four per million in a high energy state). This means that the energy released by the water protons is not particularly strong however, an image can still be visualized due to the sensitivity of MRI detectors (Wahsner et al., 2019).

Once this occurs, there are two mechanisms through which the hydrogen atom can return to the lower energy state, through a T1 or T2 relaxation (Figure 2). T1 relaxation is the energy exchange between the proton and the surrounding water molecules during the return to thermal equilibrium, whereas T2 (or spin-spin) relaxation time refers to the interactions within the water molecules themselves (discussed further below). This relaxation time is the time that it takes for the central axis to re-align itself with B_0 (Grover et al., 2015; Lin & Brown, 2007). Depending on the type of scan that is conducted, either a T1 or T2 relaxation will be prioritized by the MRI (Wahsner et al., 2019). Although the endogenous relaxation times (without the addition of GBCAs) of bulk water protons will be sufficient for many diagnoses, there are

limitations with contrast when MRI is used for CNS, gastrointestinal, and cancer diagnoses (Leung, 2012). This lack of contrast is due to the relative similarity of the water proton concentration between the tissue of interest and bordering tissues, making it difficult for the MRI machine to distinguish minor differences in signals (Burtea et al., 2008).

Over the first eight years of clinical use, the limitations of MRI with were realized. Beginning in 1988, bioinorganic drugs that could augment the contrast of the MR images became increasingly popular (Lohrke et al., 2016). These drugs are highly paramagnetic and can affect the relaxation times of protons, which affect the signal intensity picked up by the MRI detector (Wood & Hardy, 1993). These drugs have increased the effectiveness of MRI through improving image contrast, brightness, and clarity (Lohrke et al., 2016).

USE OF CONTRAST AGENTS IN MRI

Currently, paramagnetic drugs used in MRI are almost exclusively gadolinium(III) based chelates due to their ability to impact relaxation time of bulk water protons (Caravan et al., 1999). There are eight GBCAs that have been used in clinical settings, and 7 of these GBCAs are approved for imaging of the CNS (Kanal et al., 2014). Other contrast agents have also been investigated, including manganese(II)- and iron(III)-based drugs (Wahsner et al., 2019). These alternative contrast agents are less effective than gadolinium(III) based drugs, but they are less toxic (see Limitations) (Morcos, 2008).

GBCAs provide a non-invasive method to visualize deep anatomical structures. For example, analyzing vascular permeability to detect cancer, aneurysms, and blockages would otherwise require deep surgical intervention without GBCAs (Smith et al., 1981; Wahsner et al., 2019). In addition, GBCAs have an immediate effect on MRI clarity and do not release ionizing radiation, making them safe and clinically practical (Hermann et al., 2008). Lastly, GBCAs are effective due to their ability to shorten the speed of T1 relaxation pathways in bulk water protons (Weinmann et al., 1984). Shorter T1 relaxation times have a direct correlation to increases in image contrast (Wahsner et al., 2019).

Before discussing how GBCAs affect T1 relaxation, we must first address the chemical characteristics of gadolinium.

CHEMICAL CHARACTERISTICS OF GADOLINIUM

The structural and magnetic qualities of gadolinium allow it to fulfill its function of increasing MRI clarity and contrast. Although the following characteristics are interrelated, they both contribute specific effects to the bulk water protons.

Coordination Geometry

Gadolinium(III) is stable with a coordination number (CN) of 9, in part due to its small size compared to other lanthanide metals. This high CN allows for the attachment of highly chelating (polydentate) ligands, meaning there are numerous points of attachment to the central metal atom, while still leaving one attachment point for the water proton (Caravan et al., 1999; Wahsner et al., 2019). This is important because more attachment points between the metal and the ligand will increase the stability of the whole complex. Since gadolinium is a toxic heavy metal, this high affinity between the gadolinium atom and the attached ligands is crucial to avoid the dissociation of the ligands in vivo

(Bellin & Van Der Molen, 2008). All the GBCAs that are approved by the US Food and Drug Association (FDA) have an octadentate polyaminopolycarboxylato-based ligand which is highly chelating and makes the overall molecule stable (Wahsner et al., 2019) (Figure 3).

Paramagnetic Qualities and Relaxation Time

In addition to gadolinium's ability to maintain a high CN, gadolinium is a paramagnetic f-block lanthanide metal. The gadolinium atom has 7 unpaired electrons, which allow the atom to interact strongly with an external magnetic field (Caravan et al., 1999; Wahsner et al., 2019). Gadolinium's high CN and its paramagnetic properties synergistically allow gadolinium-based drugs to influence the T1 and T2 relaxation times of water (Lin & Brown, 2007). After the RF pulse is administered, the central axis of the water proton is bumped out of alignment with B_0 . As mentioned above, the T1 relaxation is the energy exchange between the water proton and the surrounding water molecules while it relaxes back to an equilibrium state. In pure water, the T1 relaxation is slow due to a high degree of water saturation; in human tissues, the T1 relaxation of water protons is faster due to water's interactions with macrocyclic biochemical molecules and endogenous paramagnetic compounds (Rooney et al., 2007;

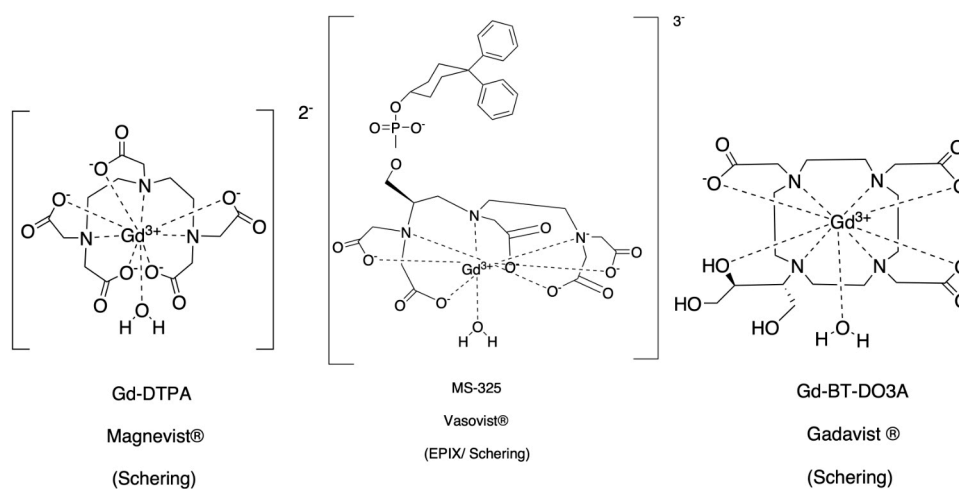


Figure 3 Three gadolinium(III)-based contrast agents, including their chemical codes, tradenames, and manufacturers. These examples depict the two ligand structures, linear and macrocyclic. Both Gd-DTPA and MS-325 have linear ligands, whereas Gd-BT-DO3A is macrocyclic. Further, MS-325 contains an extra biphenylcyclohexane group to interact with human serum albumin for cardiovascular-related MRI scans. Adapted from PubChem Compound Summary (National Centre for Biotechnology Information, 2020a, 2020b, 2020c).

Table 1 Clinically used Gadolinium(III)-Based Contrast Agents

Tradename	Chemical name and code	Ligand Structure	T1 Impacts ($r_1/\text{mM}^{-1}\text{s}^{-1}$)	Clearance/ Lifetime	Stability (logK)	Dosage
Dotarem® Clariscan®	Gadoterate meglumine (Gd-DOTA)	Macrocyclic	4.2	Renal	25.3	0.1mmol kg ⁻¹
ProHance®	Gadoteridol (Gd-HPDO3A)	Macrocyclic	4.4	Renal, 1.57h	23.8	0.1mmol kg ⁻¹
Gadovist® (EU)/ Gadavist® (US)	Gadobutrol (Gd-DO3A-butrol)	Macrocyclic	5.3	Renal	20.8	0.1mmol kg ⁻¹
Magnevist®	Gadopentetate dimeglumine (Gd-DTPA)	Linear	4.3	Renal, 1.60h	22.2	0.1-0.3mmol kg ⁻¹
Omniscan®	Gadodiamide (Gd-DTPA-BMA)	Linear	4.6	Renal, 1.30h	16.8	0.1-0.2mmol kg ⁻¹
Optimark®	Gadoversetamide (Gd-DTPA-BMEA)	Linear	5.2	Renal, 1.73h	16.8	0.1mmol kg ⁻¹
Multihance®	Gadobenate dimeglumine (Gd-BOPTA)	Linear	6.7	Renal, Hepatic, 1.2-2h	18.4	0.05-0.1mmol kg ⁻¹

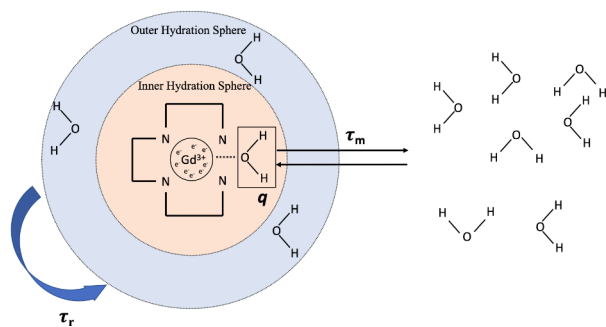


Figure 4 Mechanism of action of GBCAs. After injection into the patient, the GBCA affects bulk water protons throughout the body. There are effects on protons directly interacting with the gadolinium(III) centre (in the inner hydration sphere), as well as some secondary stabilization on protons in the outer hydration sphere. q refers to the number of protons interacting with the metal centre. τ_m refers to the time for water exchange. τ_r refers to the molecular rotation of GBCAs. τ_r has the greatest impact on the T1 relaxation times because molecular rotation creates a magnetic field that interacts with protons in the inner and outer spheres.

Wahsner et al., 2019). T2 (or spin-spin) relaxation time refers to the energetic interactions in the water molecules. T2 relaxation is faster than T1 relaxation and is governed by the different spins in the water molecule becoming out of phase after interacting with the RF magnetic field (de Graaf et al., 2006; Stanisz et al., 2005; Stevenson et al., 2000). MRI scans can be tuned such that they prioritize either T1 or T2 relaxation of the protons (Wahsner et al., 2019). In T1-weighted scans, tissue types with shorter T1 times result in brighter regions in the image, whereas in T2-weighted scans, tissue types with longer T2 times result in brighter regions. Thus, GBCAs are primarily used in T1 scans as they increase the contrast in T1 scans and decrease the contrast in T2 scans (Mitchell, 1996; Wood & Hardy, 1993). The paramagnetic qualities of GBCAs create local magnetic fields that increase the efficiency of T1 relaxation upon coordination with the bulk water protons, which will be discussed below.

GADOLINIUM CONTRAST AGENTS AND MECHANISMS OF ACTION

Since all clinically approved GBCAs interact with bulk water protons similarly, the following three examples were selected to depict the main ligand classifications (linear and macrocyclic) and the effects of attaching specific ligand groups (Figure 3).

These agents outline some of the key ligand design concepts of GBCAs. Gd-DTPA (Magnevist®; Schering) was the first GBCA and was developed in 1988 (Lohrke et al., 2016). This molecule has a linear pentetic acid (DTPA) ligand, which increases the kinetic activity of the drug (Wahsner et al., 2019). This drug is stable and has remained a staple in MRI clinics worldwide. MS-325 (Vasovist®; EPIX/ Schering) has a similar linear chelate to Gd-DTPA however, it also contains a biphenylcyclohexane group bound through a phosphodiester bond to the ligand base. Although prohibited for use in CNS scans (as it cannot pass the blood brain barrier), the biphenyl group in MS-325 can interact with human serum albumin protein in the blood (Hermann et al., 2008; Leung, 2012; Wahsner et al., 2019). Due to this interaction, MS-325 is used for MR angiography of the aorto-iliac vessels (Laufer et al., 1998). Lastly, Gd-BT-DO3A (Gadavist®; Schering) makes use of a macrocyclic ligand to increase the stability of the

metal-ligand complex (Morcos, 2008). Due to this stability, it is an ideal GBCA candidate and is frequently used in clinical settings (Hermann et al., 2008). Table 1 shows 8 GBCAs approved by the FDA, as well as their structures, their T1 impacts (ability to increase T1 relaxation time), their lifetime in the body, their measurements of stability, as well as their dosage (Gadavist and Gadovist are considered two drugs, but have the same structure) (Hermann et al., 2008). One notable aspect of all the GBCA candidates is their high dosages, due to their lack of tissue specificity in the body (Leung, 2012). As such, the thermodynamic stability of these drugs is crucial for safe clinical use due to the widespread toxicity resulting from the dissociation of the ligand from the metal centre (Hermann et al., 2008).

MECHANISM OF ACTION OF GADOLINIUM CONTRAST AGENTS

Once administered to the patient (either intravenously, orally, or by inhalation), the GBCA travels (non-specifically) towards the site of inflammation (Wahsner et al., 2019). The Brownian motion of the drug creates a changing magnetic field that alters the T1 relaxation time of the nearby protons (Hermann et al., 2008; Bellin & Van Der Molen, 2008; Caravan et al., 1999). There are 4 main metrics through which the efficiency of GBCA-mediated T1 relaxation is measured: (1) the number of water molecules bound to the complex (q); (2) the mean residence time (τ_m); (3) the number and residence time of the water molecules in the second (outer) sphere; and (4) the rotational correlation time (τ_r) of the GBCA (Dumas et al., 2010). As depicted in Figure 3, GBCAs form complexes with one water molecule at a time ($q = 1$). Although possible to have cases where $q = 2$, this is uncommon due to the destabilization of the rest of the molecule (Laufer, 1987; Lohrke et al., 2016).

Resistance time (τ_m) is the time of water exchange with the metal centre and is affected by the number and residency time of water molecules in the outer hydration sphere (Figure 4) (Wahsner et al., 2019). Increases in peripheral proton number (i.e. the number of protons around the GBCA) and residency time will facilitate the formation of a bond between the proton and the gadolinium(III) centre, causing faster T1 relaxation (Lohrke et al., 2016). This strength of the bond between the gadolinium centre and the proton needs to be deliberately tuned such that it allows the exchange process to occur (Grover et al., 2015).

The most important metric of T1 relaxation is the rotational correlation time (τ_r), or molecular tumbling, of the GBCA (Figure 4). Although variable, molecular tumbling induces proton relaxation through creating a fluctuating magnetic field (Caravan, 2006; Barrett et al., 2006; Jacques et al., 2010; Laufer, 1987). To make this an effective process, the complex needs to create a fast and transient dative bond with water molecules (Figure 4) (Barrett et al., 2006; Laufer, 1987). This bond occurs quickly, in the order of nanoseconds, such that the T1 relaxation of multiple water protons can be increased during the administration of these drugs (Wahsner et al., 2019).

LIMITATIONS OF GADOLINIUM-BASED CONTRAST AGENTS

Though GBCAs can affect T1 relaxation and hence MR image contrast, there are limitations to these drugs. During the first 20

years of GBCA usage in clinical settings, GBCAs showed minimal side effects and thus were considered to be some of the safest drugs (Lohrke et al., 2016). In 2006, GBCAs were linked to fatal nephrogenic systemic fibrosis (NSF) in patients with kidney failure (Grobner, 2006; Morcos, 2007; Wahsner et al., 2019). Since GBCAs lack tissue specificity, they travel the entirety of the bloodstream upon injection. Due to this, a high dosage (e.g., 0.1 mmol/kg) is required to achieve optimal imaging, resulting in the possibility of gadolinium(III) disassociation with its chelates and thus toxicity effects (Hermann et al., 2008). Although the disassociation is unlikely due to the high stability of the CN = 9 complexes, patients with kidney failure may not be able to excrete the drugs, rendering them susceptible to NSF (Marckmann et al., 2006). NSF symptoms in kidney failure patients arose 2-4 weeks after GBCA administration, indicative of a lack of excretion (Morcos, 2008).

In addition to the challenges with clearing these drugs from the body, there is inherent toxicity with injecting high dosages of heavy metals (Hermann et al., 2008). With GBCAs, there has been evidence of damage to the spleen and liver, inhibition of enzymes, and the blocking of calcium channels (Morcos, 2008). GBCAs may also accumulate in the brain, causing continued T1 shortening in deep gray matter (Tedeschi et al., 2018). Although no CNS health effects have been documented for gadolinium, more research needs to be done to analyze the effects of intercranial accumulation (Wahsner et al., 2019). Increasing tissue specificity of GBCAs will minimize dosage to reduce adverse side effects of the contrast agent. Alternatively, contrast agents that are more effective at increasing T1 relaxation times have shown promise in the development of lower dosage drugs (e.g., targeted agents, such as EP-2104R, that increase contrast in specific tissues of interest) (Caravan et al., 2007; Jacques et al., 2010; Spuentrup et al., 2007; Vymazal et al., 2009; Wahsner et al., 2019).

CONCLUDING REMARKS AND FUTURE DIRECTIONS

Gadolinium(III)-based contrast agents have demonstrated a productive application of inorganic chemistry to the field of medicine. Their ability to increase the T1 relaxation times of bulk water protons creates a greater image contrast, resulting in clearer images and better diagnoses. This has implications for certain diseases that would otherwise require highly invasive intervention, such as cancer (Gore et al., 2011). Nonetheless, GBCAs have significant limitations with toxicity and dosage, causing researchers to work towards finding other contrast agents. As mentioned previously, manganese(II), and iron(III) have been shown to effectively increase the T1 relaxation rate for bulk water protons (Lauffer, 1987). In addition, chemical exchange saturation transfer (CEST), redox transfer agents, neurotransmitter agents, and temperature responsive agents are found to be potential avenues for creating highly contrasted MRI images without adverse toxic effects (Klohs & Rudin, 2011; Wahsner et al., 2019). Nonetheless, GBCAs are currently the most effective contrast agents and provide a powerful method for clinicians to make non-invasive diagnoses.

The author would like to thank to Dr. Emma Davy for her support with this project and teaching a great class.

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The metallurgical troubles of Hastelloy-N in molten salt reactors

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ABSTRACT Many nuclear energy companies, including two based in Canada (Moltex Energy and Terrestrial Energy), have become interested in reactors that use molten salts in place of water as coolant and as a medium to hold the fuel. They draw technical inspiration from the Molten Salt Reactor Experiment (MSRE), a reactor that operated from 1965 to 1969 at the Oak Ridge National Laboratory, Tennessee (ORNL). One of the challenges with molten salt reactors involves the metallurgical materials used to manufacture the various reactor components, which would have to work in highly corrosive environments at elevated temperatures. To solve this problem, the MSRE developed Hastelloy-N, an alloy high in nickel and molybdenum but low in chromium, to manufacture most metallic parts of the reactor, including the MSRE reactor vessel, piping, and pumps for all coolant loops and heat exchangers. Hastelloy-N had superior corrosion properties to the previously favoured Incoloy (a high nickel alloy for high-temperature use), which was used in salt-containing systems for the old Aircraft Reactor Program. One of the problems experienced by Incoloy was that because of the choice of structural material, the molten salt had to be separated from any beryllium contamination. After the MSRE was shut down in 1969, a number of studies showed that Hastelloy-N had developed cracks, leading to a deterioration in mechanical properties such as creep strength. This review examines the literature and summarizes the technical problems associated with using Hastelloy-N as a nuclear construction material. These material properties are essential for assessing the feasibility of the molten salt reactor designs proposed for Canada.

INTRODUCTION

A molten salt reactor (MSR) is a variety of nuclear fission reactors where the nuclear fuel is mixed with very hot, molten fluoride or chloride salt. It is different from traditional nuclear reactors, such as the CANDU Heavy Water Reactors or Light Water Reactors, where the fuel is in solid form. The first molten salt reactor design was developed in Oak Ridge National Laboratory, Tennessee (ORNL) as part of the U.S. nuclear bomber program, but it only operated for ten days in November 1954 (Rosenthal, 2010). However, this would soon inspire the landmark Molten Salt Reactor Experiment (MSRE), which inspired dozens of reactor designs in the 21st century. The first substantial test molten salt reactor in the world was the MSRE operated from 1964 to 1969 at the ORNL (Rosenthal, 2010). The ORNL MSRE operated on two "systems" or loops, one for the fuel system and reactor and the other for a heat exchanger to exchange heat from the fuel to the cooling salt (Figure 1). The heat flows for the MSRE are also included in Figure 1. The composition of the fuel salt used in the MSRE was $\text{LiF-BeF}_2\text{-ZrF}_4\text{-UF}_4$. The coolant has the same composition except without uranium dissolved (a LiF-BeF_2 compound). Two main experiments were performed: first, scientists used a graphite-moderated U-235/Thorium fuel cycle with uranium and thorium being in the same salt or separated by a graphite barrier, respectively; then, experiments using U-233 began in 1968 (Rosenthal et al., 1970).

One of the challenges with molten salt reactors involves the metallurgical materials used to manufacture the various reactor components, which would have to work in highly corrosive environments at elevated temperatures. The material used for reactor components such as piping and containment in the MSRE was Hastelloy-N (the trademark name for INOR-8), invented by Henry Inouye, William Manly, and Thomas Roche from ORNL in the early 1960s (Pike, 2014). Hastelloy-N is a weldable nickel-based metal alloy with high molybdenum content (Figure 2) (Forsberg, 2006; Rosenthal et al., 1967). This alloy was developed explicitly for use as a salt-facing structural material for the MSRE reactor vessel, piping, and pumps for all coolant loops and heat exchangers (Figure 1). The high nickel and molybdenum but low chromium content made Hastelloy-N highly compatible with fluoride salt environments

Published online
May 31, 2022

Citation

Chong, M. (2022). The Metallurgical Troubles of Hastelloy-N in Molten Salt Reactors. *CJUR*, 7(1), 38-44.

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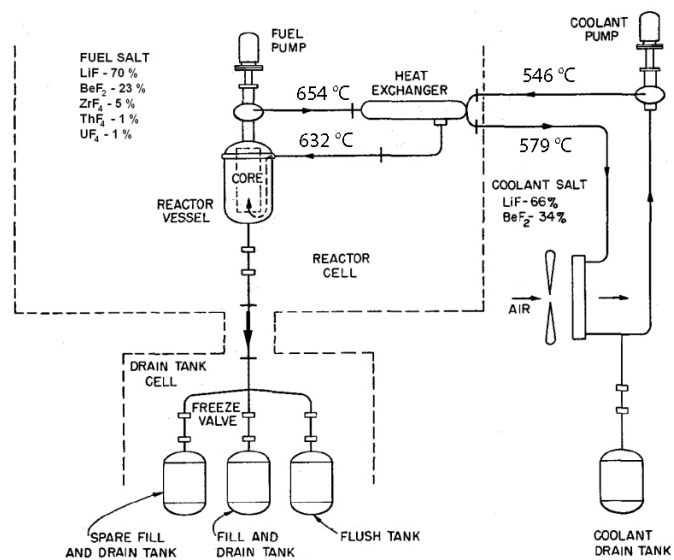
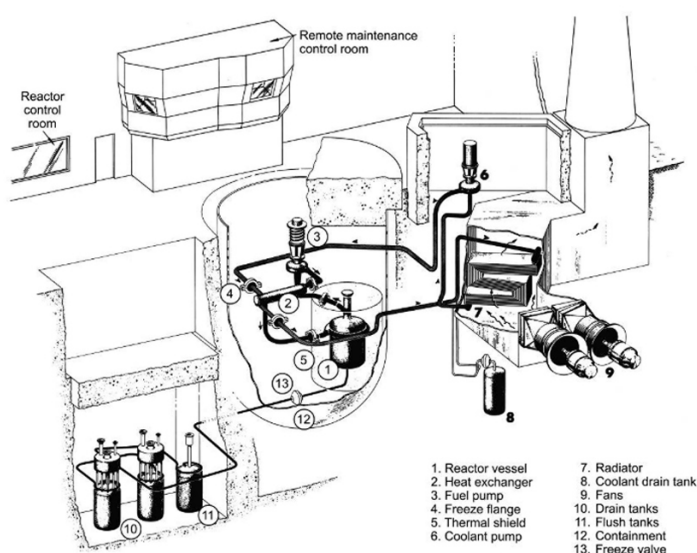


Figure 1 Schematic of the MSRE and Flow of Heat (Luzzi et al., 2012; Rosenthal, 2010)



Figure 2 Sample of Hastelloy-N (Yoshioka, 2013)

Database	Search terms
Office of Scientific and Technical Information (OSTI), US Department of Energy	MSRE AND Hastelloy-N, MSRE AND Metallurgy, MSRE AND problems, MSRE and "Operational problems", ORNL AND MSRE, INOR-8
HathiTrust	MSRE AND Hastelloy-N, MSRE AND Metallurgy, MSRE AND research, Hastelloy-N, INOR-8, MSRE AND Corrosion
Nuclear Safety, Government of Canada	Hastelloy-N, Moltex Energy, Terrestrial Energy, "Molten Salt Reactors"
International Atomic Energy Agency Advanced Reactors Information System (IAEA ARIS)	IMSR, SSR-W, MSR, MSRE, Terrestrial Energy, Moltex Energy, Hastelloy-N
ORNL, Oak Ridge National Research Laboratory	MSRE AND Hastelloy-N, MSRE AND Metallurgy, MSRE AND research, Hastelloy-N, MSRE AND Corrosion

Table 1 Databases and Search Terms Consulted

(Koger, 1972). It was superior in corrosion properties to the Incoloy (a high nickel alloy for high-temperature use) used in salt-containing systems for the earlier Aircraft Reactor Program (Lyon et al., 1969). However, the use of Hastelloy-N came with many technical challenges pertaining to nuclear material selection problems and mechanical deficiencies of Hastelloy-N as a construction material for molten salt reactors. This is relevant to Canadian reactors intended to be built in the upcoming years, as citizens residing near planned reactors have limited access to information regarding the material selection of these nuclear reactors, despite substantial portions of taxpayer money funding these reactors and the potential environmental and safety issues with nuclear power.

The reactors of discussion will be Terrestrial Energy's Integral Molten Salt Reactor (IMSR) and Moltex Energy's SSR-Wasteburner (SSR-W). The IMSR is slated for the Darlington, Ontario site (News, 2020) and the SSR-W for the Point Lepreau, New Brunswick site (O'Sullivan, 2021). Below, I summarized the results of a systematic review of experimental studies and technical reports from the construction of past and future molten salt reactors. Significant publications from the ORNL in the 1960s to present-day research regarding the IMSR and SSR-W were

consulted in a methodical scan of well-known databases. National and international standards regarding metallic nuclear construction materials will also be examined.

METHODS

Table 1 lists databases and search terms used to complete this literature review. A significant quantity of the literature surrounding nuclear reactors is considered either high-level government security or proprietary information such that it is publicly inaccessible. Notably, it was challenging to find detailed designs or research and development information regarding the Moltex SSR-W and Terrestrial Energy IMSR. For example, the values pertaining to the efficacy of zirconium alloying experiments as performed by Terrestrial Energy are not publicly available at the time of manuscript submission.

DISCUSSION

Numerous studies throughout the last six decades have been conducted regarding the properties of Hastelloy-N (Koger, 1972;

McCoy, 1967; Scott, 2017; Wright & Sham, 2018) and the lack of specific metrics for approval by Canadian regulatory agencies (Commission, 2021b). Databases such as HathiTrust and Office of Scientific and Technical Information, U.S. Department of Energy has released significant information on the degradation of Hastelloy-N in the MSRE. However, limited information is available through federal agencies, published technical reports, or the company's website regarding critical material selection choices. The use of Hastelloy-N is not recommended until a solution is developed that is corrosion and irradiation resistant within the environment of the Molten Salt Reactors will be presented.

Inherent Mechanical Problems of Hastelloy-N

With the advent of molten salt fuels and coolants, Hastelloy-N had to be specifically designed to be robust in a highly radioactive and corrosive environment. The initial metallurgical decision of nickel-based alloying with a high level of molybdenum should have made Hastelloy-N operationally adequate but ultimately resulted in severe mechanical problems. An overview of the inherent mechanical problems will be introduced, followed by a brief explanation of the theories and mechanisms of corrosion experienced by Hastelloy-N. The required properties of Hastelloy-N are derived from the environment to which it is exposed. Inside a molten salt reactor, the Hastelloy-N structural components would be exposed to corrosive salts at high temperatures and high radiation levels. Thus, the constituent metal must be capable of withstanding irradiation, high temperatures, and corrosion while being compatible with other confinement and neutron moderator materials. The expected operating conditions as a range of limits are listed in Table 2 below. The question mark indicated information not currently available on searched databases.

Table 2 Expected Operating Condition in MSRE, IMSR and SSR-W (Leblanc, 2013; O'Sullivan, 2021; Rosenthal, 2010)

	MSRE	IMSR (Terrestrial Energy)	SSR-W (Moltex)
Fuel inlet temperature °C	635	625-660	?
Fuel outlet temperature °C	663	670-700	600
Radiation Dose (neutrons/cm ²)	5.00E+19	5.60E+14	?
Full Scale Plant Design Life (Year)	30	60	60

In the MSRE, temperatures reached up to 663°C in the outlet. More recent molten salt reactors, such as the Canadian designs that will be addressed later, reach up to 700°C (IAEA, 2016). It is currently unknown how similar the radiation exposures will be. Furthermore, any alloy chosen for a molten-salt reactor would have to be resistant to intergranular attack by tellurium and helium embrittlement caused by bubbling (Pelayo & Edwards, 2016). As its name suggested, intergranular attack is a form of corrosion occurring preferentially along grain boundaries in particular alloys and environments, leading to macroscopic deterioration. On the other hand, helium embrittlement is caused by bubbles formed as a secondary product of fission technology and severely reduces the ductility of a metal (Li et al., 2019). Finally, the selected material would have to be weldable and resistant to cracking after welding (Koger, 1972).

Prior to the early 1970s, Hastelloy-N was viewed as the most

promising container material for molten fluorides exposed to 800°C radioactive environments (Koger, 1972). The performance of Hastelloy-N was judged to be adequate during the operation of the MSRE until routine inspection in the later years of operation was conducted (Koger, 1972; Wright & Sham, 2018). The promise of Hastelloy-N as a suitable material proved illusory as two primary deficiencies became apparent:

1. Embrittlement at elevated temperatures above ~700°C resulting in decreased strength (McCoy, 1967)
2. The presence of intergranular surface cracking (Koger, 1972).

The deficiency of embrittlement as caused by thermal neutrons is directly informed by the type of reactor designed and will thus not be given further consideration (McCoy, 1967). However, the exact mechanism of intergranular corrosion will be further explored owing to the information presently available on databases.

Hastelloy-N and Surface Cracking

Subsequent studies on samples from the reactor showed that Hastelloy-N also suffered from surface cracking due to tellurium (Laboratory, 1973). Tellurium is a product of the fission reactions that produce energy in nuclear reactors and tends to concentrate on the grain boundaries of metals.

ORNL researchers have argued that if the MSRE had operated for 30 years, the estimated lifetime determined at ORNL in the 1960s (Lyon et al., 1969), the depth of cracking observed due to tellurium would not be acceptable (McCoy & McNabb B, 1972). To provide some commentary on chemistry principles, if the fuel compounds are more stable than the structural materials, the salts and the metal corrosion rate should be low (this phenomenon will be further discussed shortly). However, the relative ranking of the metals indicates that molybdenum and nickel are least likely to form fluorides while chromium is most likely. Thus, a good container material for these salts would be a nickel or molybdenum base alloy with minimum quantities of chromium and iron (Lyon et al., 1969; McCoy & McNabb, 1972).

One solution proposed in 1973 involved adding titanium to cure the cracking by strengthening the radiation immunity of Hastelloy-N (Laboratory, 1973). However, subsequent studies found that titanium did not mitigate tellurium embrittlement (Wright & Sham T L, 2018). It is unknown if there are alternative materials that could ameliorate the surface-cracking problem in molten salt reactors, but such research is worth conducting.

Mechanism of Corrosion

The chemical composition of Hastelloy-N plays a significant part in the mechanism by which corrosion occurs. Hastelloy-N is Ni-based, containing a weight composition of roughly 76% Ni - 16% Mo - 7% Cr - 1% Fe and a small number of other elements (Busby et al., 2019). The Gibbs free energy of formation is used to measure the stability of a chemical compound. A compound tends to be stable if the free energy is negative, and the stability is greater the more negative the Gibbs free energy. Table 3 shows the relative stabilities of several fluorides of interest per mol of fluorine at 527



Figure 3 Photomicrograph of a Cross-Section of Outlet Pipe Showing Inner Surface and Crack. Etchant: Aqua regia (Mccoy & McNabb, 1972)

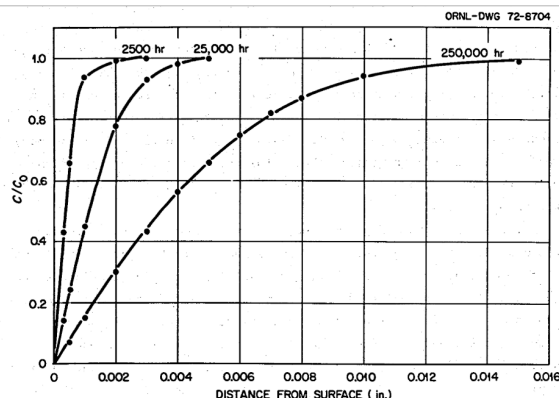


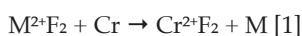
Figure 4 Calculated Chromium Profiles at 650°C in INOR-8 Assuming Zero Surface Concentration of Chromium (Mccoy & McNabb, 1972)

Table 3 Standard Free Energies of Formation of Fluorides in a Molten Salt System at 527°C and 727°C (Mccoy & McNabb, 1972)

Fluoride	$-\Delta G_f$ kJ/mol Fluorine (~ 527°C)	$-\Delta G_f$ kJ/mol Fluorine (~ 727°C)
CrF ₂	334.1	320.7
MoF ₂	310.7	302.7
NiF ₂	266.7	251.6
FeF ₂	297.3	284.3
UF ₄	415.7	399.8

and 727° C, including the potential fuel salt constituents and the structural metals under consideration (DeVan et al., 1995). The pressure at which the standard conditions were measured was not given in the original source.

The corrosion rate of chromium increases in a logarithmic fashion depending on time and distance from the surface (Mccoy & McNabb, 1972) as depicted in Figure 3. Corrosion proceeds by the selective oxidation of chromium at the hotter loop surfaces and the reduction and deposition of chromium at the cooler loop surfaces (DeVan et al., 1995). This is illustrated by equation [1]:



where M: Fe, Ni, Mo, Mn, ... (DeVan et al., 1995)

The problem of corrosion is particularly difficult in the MSRE, as any protective oxide coatings on metallic surfaces are readily dissolved inside the molten salt (Muránsky et al., 2019). A potential solution would be to utilize lower concentrations of relatively reactive alloys such as chromium and higher levels of less reactive metals like nickel. However, the corrosion problems could not be entirely eliminated, only slowed down (Scott, 2019), causing difficulty in long-term operations.

International Regulation of Hastelloy-N

In 1963, the American Society of Mechanical Engineers (ASME) responded to a U.S. Atomic Energy Commission proposal to regulate nuclear plant construction and operations by creating engineering codes and standards (American Society of Mechanical Engineers, 2020). Today, ASME codes and standards are widely

used in manufacturing standards and facilitate licensing in conjunction with the U.S. Nuclear Regulatory Commission (Wright & Sham, 2018).

As of 2018, Hastelloy-N had not been qualified for use in nuclear components by the ASME (Wright and Sham, 2018).

In Canada, the materials of nuclear power plants are governed by the following codes and legislations:

"For steel containment, the design should be based on ASCE 43-05 (SDC 5), 2010 ASME Boiler and Pressure Vessel Code, Section III: Rules for Construction of Nuclear Power Plant Components, Division 1, Subsection NE: Class MC Components and US NRC Regulatory Guide 1.57, Design Limits and Loading Combinations for Metal Primary Reactor Containment System Components." (Commission, 2021b)

In order to obtain a license to construct a new nuclear power plant under Canadian Legislation, the following information on reactor materials must be provided with full engineering justification:

1. "chemical, physical and mechanical properties
2. resistance to corrosion
3. dimensional stability, strength, toughness, crack tolerance, and hardness
4. microstructure and material fabrication details, where this is important" (Commission, 2021a)

According to the above legislation, it would be challenging to provide full engineering justification for Hastelloy-N due to the significant corrosion problems experienced by the MSRE. In discussing the potential qualification of Hastelloy-N, two

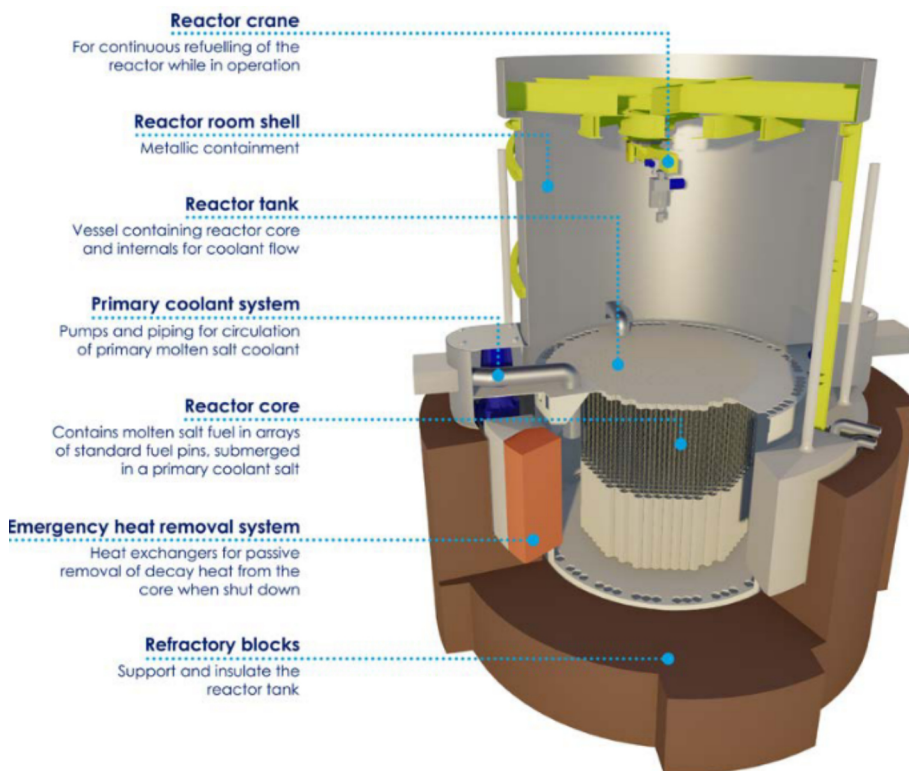


Figure 5 Moltex SSR-W (O'Sullivan, 2021)

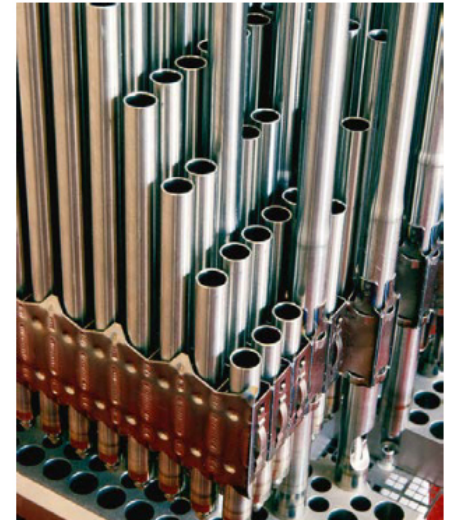


Figure 6 Moltex Fuel Pin Assembly (O'Sullivan, 2021)

members of the Idaho National Laboratory's Advanced Reactor Technologies Program argued that research still indicated the helium embrittlement above 700°C. Wright and Sham (2018) concluded that Hastelloy-N does not have sufficient elevated temperature strength for extended use within the decades-long lifetime of newer molten salt reactors. Therefore, Hastelloy-N should not be accepted in Canada as a nuclear construction material.

Hastelloy-N in Proposed Canadian Reactors from Moltex Energy and Terrestrial Energy

Moltex Energy and Terrestrial Energy are the two largest molten salt reactor companies, the former received substantial financial assistance from the Canadian Federal Government. Both companies have passed the first phase of the Canadian Safety Nuclear Association Pre-Licensing Vendor Review with the goal of construction by 2030 (Moltex, 2021; Terrestrial, 2021).

Moltex Energy is currently developing the Stable Salt Reactor-Wasteburner (SSR-W) (Figure 4), which incorporates the general design features of a molten salt reactor for the Point Lepreau Site in New Brunswick (O'Sullivan, 2021).

In the SSR-W, fission reactions occur within tubes of molten salt separated from the liquid coolant (SMR Roadmap Technology Working Group, 2018) (Figure 5).

It seems implied by the available literature that Moltex intends to use Hastelloy-N for fuel pins (Figure 6) (Fredrickson et al., 2018). Moltex technology reported that by adding zirconium to the chloride salt, the corrosion of Hastelloy-N was tremendously reduced by an unspecified amount (Fredrickson et al., 2018).

Furthermore, a public report by Moltex Energy claimed that the small addition of zirconium to each Hastelloy-N fuel tube (O'Sullivan, 2021) has the effect of recovering any oxidizing species inside the chloride salt, which are plentiful due to the fission reaction (Scott, n.d.). However, adding zirconium to Hastelloy-N might complicate the manufacturing processes and make the material difficult to weld or susceptible to stress corrosion cracking (Wright & Sham, 2018). These long-term effects of zirconium alloying are unknown and should be explored for reliable long-term reactor operation. In addition, further research is needed to elucidate the relationship between irradiation and the mechanical effects of zirconium alloying within aggressive salt reactor conditions (Fredrickson et al., 2018).

Terrestrial Energy is developing a 400-megawatt molten salt reactor known as the Integral Molten Salt Reactor (IMSR) (IAEA, 2016), proposed to be built in Darlington, Ontario. The IMSR uses molten salt as coolant and fuel. The IMSR features integrated primary reactor components, including the graphite moderator, into a sealed and replaceable reactor core (Figure 7). According to the company website, the design of the IMSR references those of test reactors at the ORNL, but the specific aspects borrowed are unclear (Lyman, 2021; Terrestrial Energy, 2018). In a 2015 report, Terrestrial Energy listed Hastelloy-N as a candidate material for vessel and primary piping (Berenfeld et al., 2015). However, the Advanced Reactors Information System (ARIS) by the International Atomic Energy Agency (IAEA) lists the material of choice for the IMSR as SS316H or Alloy N for the base material and Incoloy 800H for the steam generator (IAEA, 2016). Later, an active patent by Terrestrial Energy that was renewed in 2020 listed Hastelloy-N to be used for the guard vessel to contain the IMSR core unit and the outer vessel (Figure 7) (Leblanc, 2013).

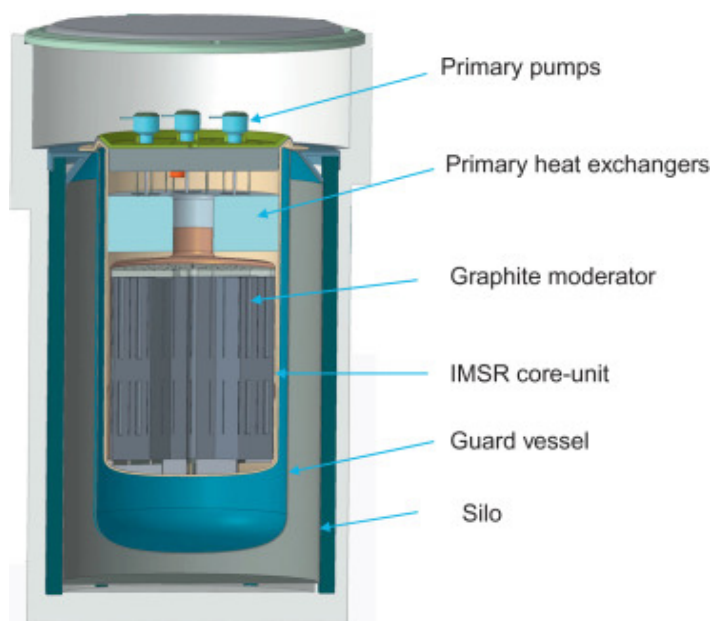


Figure 7 IMSR Reactor Core (LeBlanc & Rodenburg, 2017)

There is a possibility that Hastelloy-N would be an appropriate construction material if not exposed to a salt face or high levels of radiation, or if only used for a very short duration. In the case of using it as material for the outer vessel Terrestrial Energy has proposed that the entire core of the reactor (including primary components) could be sealed into a single replaceable core unit. In theory, the core unit would be replaced every seven years, so the problem of Hastelloy-N corrosion could potentially be mitigated. However, further R&D should be conducted, and the public should be made aware of any new developments.

CONCLUSION

The IMSR and SSR-W share key features of a historical test reactor, the Molten Salt Reactor Experiment (MSRE), which ran from 1964 to 1969. The MSRE made heavy use of Hastelloy-N as a salt-facing structural material for the reactor vessel, piping, and pumps for all coolant loops and heat exchangers. The performance of Hastelloy-N was judged to be adequate during the operation of the MSRE until routine inspection in the later years of operation was conducted (Koger, 1972; Wright & Sham, 2018). ORNL researchers have argued that if the MSRE had operated for the predicted lifetime of 30 years (Lyon et al., 1969), the depth of cracking observed due to tellurium would have been unacceptable (Mccoy & McNabb B, 1972). The precedent set by the MSRE does not lend confidence to future applications.

Many nations and co-operations, in particular Canada, have expressed substantial interest in Molten Salt Reactors. Many are considering the use of Hastelloy-N for various molten salt reactor components. The IMSR from Terrestrial Energy would use molten salt reactor technology and is intended to be constructed in Darlington, Ontario. The IMSR intends to use Hastelloy-N as material to contain both the reactor core and outer vessel, where it will experience significant radiation. On the other hand, Moltex is developing a similar type of reactor called the SSR-W for Point Lepreau, New Brunswick. The SSR-W would use stationary, metal-clad fuel elements containing molten salt fuel in arrays of standard fuel pins submerged in coolant salt. These fuel pins

would contain Hastelloy-N alloyed with zirconium. However, additional R&D should be undertaken by both companies to examine the viability of the material throughout the reactor life cycle. Any significant findings should be made publicly available for the benefit of Canadians.

The evidence so far is that Hastelloy-N has many problems, including deteriorating operation above 700°C due to neutron irradiation, helium embrittlement, and intergranular cracking when exposed to the fission products within molten salt. Given these problems, scientists have recommended that ASME should not approve Hastelloy-N as a nuclear construction material. Therefore, in order to prevent possibly dangerous scenarios such as structural instability or contamination of surrounding ecological systems, Hastelloy-N should also not be used in the Canadian IMSR and SSR-W reactors. The potential risks involved are indeed significant for any government or company interested in constructing molten salt reactors.

The author would like to acknowledge Dr. MV Ramana for his continued mentorship and guidance, and peers and professors at the Department of Materials Engineering at UBC for their input and support.

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