Sciential

McMaster Undergraduate Science Journal

ISSUE 5 - DECEMBER 2020

CONTENTS

ABSTRACT

2 Implications of Vitamin D Levels in COVID-19 Morbidity and Mortality

ORIGINAL RESEARCH

4 Mapping Neodymium Model Ages of the Quebecia Terrane Near Saguenay, Quebec

ACADEMIC REVIEW

13 The Value of Manifold Learning Algorithms in Simplifying Complex Datasets for More Efficacious Analysis

21 Reviewing Inequities in Primary Care Received by Indigenous Peoples in Ontario

INFOGRAPHIC

29 COVID-19 vs. History's Pandemic

OPINION PIECE

31 The Role of Public Health Communication in Combating Vaccine Hesitancy: A Historical Comparison

DEAR READER,

Welcome to Issue 5 of *Sciential*! In the midst of a global pandemic, there has been a recent peak in interest in scientific research and some confusion regarding what that entails. As such, increasing accessibility has been our team's primary priority this year. We are thrilled to announce that we have incorporated lay summaries preceding all of our pieces. We are also excited to announce the upcoming publishing of our science communication blog, featuring lay pieces by students in any faculty at McMaster University. Announcements about this release will be updated on our social media platforms.

In contrast to previous issues, this one has opened the floor to more diverse topics in science and health, including the quality of primary health care received by Indigenous peoples in Ontario, manifold learning and its applications to topological analysis, and the geological evolution of the Grenville Province in Ontario. We also have pieces highly relevant to the ongoing global pandemic. These include research pieces comparing COVID-19 with past pandemics and outbreaks, how vitamin D levels may affect COVID-19 morbidity outcomes, and how science communication regarding public health and vaccine hesitancy from previous pandemics may affect our current situation.

We hope that you will enjoy the range and the relevance of the pieces in this issue. This term has been different from preceding ones, but our team has worked tirelessly to embrace the online environment and provide you with high-quality student work. We are incredibly grateful for the fantastic work ethic and dedication of our Senior Editors, Stefano Biasi and Reza Khorvash, and Creative Director, Youssef El-Sayes. We appreciate the diligence and creativity of the Editors, Illustrators, Graphic Designers and the Communication Coordinator on our team. We would also like to acknowledge our Co-founders, Alisa Nykolayeva and Aiman Shahid, Senior Advisor Team, Dr. Kimberley Dej, Dr. Veronica Rodriguez Moncalvo, Dr. Katie Moisse, and Science Librarian, Abeer Siddiqui, for their support.

We hope that you will enjoy Issue 5 and that you stay safe and well in these unprecedented times.

Ishita Paliwal
Editor-in-Chief

Isabel Dewey
Editor-in-Chief

@SCIENTIALJOURNAL

@MACSCIENTIAL

JOURNALS.MCMASTER.CA/
SCIENTIAL

SCIENTIAL@MCMASTER.CA

ABSTRACT

OPEN ACCESS

Implications of Vitamin D Levels in COVID-19 Morbidity and Mortality

Nahal Emami Fard[1], Niki Sadat Afjeh[1], Paniz Poursharif[2]

1. McMaster University, Biology, Class of 2021

2. McMaster University, Life Sciences, Class of 2021

Received 14 October 2020
Accepted 29 October 2020
Published 4 December 2020

SUMMARY

Recent research shows relationships between optimal vitamin D levels and better outcomes in COVID-19. Vitamin D is a hormone required for healthy bones. When its levels in the blood drop below 25 nmol/L, one is vitamin D deficient. Insufficiency is when blood vitamin D levels are below 75 nmol/L. 70% of the US population are vitamin D deficient, while 30% are vitamin D insufficient. This study analyzes three articles revealing associations between vitamin D levels and risk of death and severe health complications from COVID-19 in adults. Maghbooli et al. (2020) reports that vitamin D sufficient patients had lower risks than deficient patients of severe COVID-19 complications. A study by Raharusun et al. (2020) finds that 98.9% of vitamin D deficient COVID-19 patients and 88% with vitamin D insufficiency died. Only 4% of sufficient individuals died. Meltzer et al. (2020) reports higher rates of COVID-19 in vitamin D deficient compared to sufficient groups. Vitamin D sufficiency may activate the immune system's antiviral response. Vitamin D binds to immune cells, stimulating the production of an antibacterial protein. More studies should examine vitamin D sufficiency as a potential mitigator in COVID-19 consequences.

ABSTRACT

Vitamin D is a steroid hormone known for maintaining bone health. Vitamin D deficiency is a 25-hydroxyvitamin D (25(OH)D) serum concentration below 25 nmol/L. In contrast, vitamin D insufficiency occurs at levels below 75 nmol/L.[1] Vitamin D insufficiency and deficiency affect 70% and 30% of the US population, respectively.[1] Emerging evidence associates optimal vitamin D levels with better clinical outcomes in COVID-19.[2] This literature review analyzed three preliminary articles that explored associations between vitamin D levels, COVID-19 mortality, and risk of adverse clinical outcomes in adult hospitalized patients.[3-5] Google Scholar was used to find studies that diagnosed COVID-19 with reverse transcription (RT-PCR). In a cross-sectional analysis, Maghbooli et al. (2020) reported that vitamin D sufficient patients had a significantly lower chance (9.7%, n=77, $p=0.01$) of severe COVID-19 complications than deficient patients (32.8%, n=158, $p=0.01$).[3] This study is under review for diagnosis accuracy and sample size. A retrospective cohort study by Raharusun et al. (2020), which included active and expired cases (n=780), found that 98.9% ($p<0.001$) of vitamin D deficient COVID-19 patients and 88% ($p<0.001$) with insufficiency died, but only 4% of sufficient individuals died.[5] Lastly, a retroactive cohort study by Meltzer et al. (2020) reported higher rates of COVID-19 infection, 21.6% (95% CI, 14.0-29.2%), in vitamin D deficient groups (n=172), compared to 12.2% (95% CI, 8.5-15.4%) in sufficient groups (n=327).[4] The 25(OH)D levels were measured within one year of COVID-19 testing.[4] All studies controlled for age, sex, and comorbidities, while the first controlled for BMI and smoking, and the third controlled for race.[3-5] Vitamin D sufficiency may activate the innate and adaptive immune systems, leading to an antiviral response.[6,7] Receptor binding of vitamin D on neutrophils and macrophages stimulates cathelicidin expression, an antibacterial peptide.[7] Macrophage and T-regulatory cell quantities also increase.[7] These results reveal the need for randomized controlled studies of vitamin D sufficiency as a potential mitigator in COVID-19 outcomes.

Keywords: Vitamin D deficiency, vitamin D insufficiency, vitamin D sufficiency, COVID-19 mortality, COVID-19 morbidity

ACKNOWLEDGEMENTS

There are no acknowledgements. The authors report no conflicts of interest.

REFERENCES

(1) Liu X, Baylin A, Levy PD. Vitamin D deficiency and insufficiency among US adults: prevalence, predictors and clinical implications. Br J Nutr. 2018;119(8):928–36.

(2) Cashman KD, Dowling KG, Škrabáková Z, Gonzalez-Gross M, Valtueña J, De Henauw S, et al. Vitamin D deficiency in Europe: pandemic? Am J Clin Nutr. 2016;103(4):1033–44.

(3) Maghbooli Z, Sahraian MA, Ebrahimi M, Pazoki M, Kafan S, Tabriz HM, et al. Vitamin D sufficiency, a serum 25-hydroxyvitamin D at least 30 ng/mL reduced risk for adverse clinical outcomes in patients with COVID-19 infection. PLoS One. 2020;15(9):e0239799.

(4) Meltzer DO, Best TJ, Zhang H, Vokes T, Arora V, Solway J. Association of vitamin D status and other clinical characteristics with COVID-19 test results. JAMA Netw Open. 2020;3(9):e2019722

(5) Raharusun, P. (2020). Patterns of COVID-19 Mortality and Vitamin D: An IndonesianStudy. Available at SSRN 3585561.

(6) Rhodes JM, Subramanian S, Laird E, Griffin G, Kenny RA. Perspective: Vitamin D deficiency and COVID-19 severity - plausibly linked by latitude, ethnicity, impacts on cytokines, ACE2 and thrombosis. J Intern Med [Internet]. 2020; Available from: http://dx.doi.org/10.1111/joim.13149

(7) Siuka D, Pfeifer M, Pinter B. Vitamin D supplementation during the COVID-19 pandemic. Mayo Clin Proc. 2020;95(8):1804–5.

ARTICLE INFORMATION

Senior Editor
Stefano A. Biasi

Reviewers and Section Editors
Caitlin Reintjes, Zoya Adeel

Formatting and Illustrations
Youssef El-Sayes

Mapping Neodymium Model Ages of the Quebecia Terrane Near Saguenay, Quebec

Serena Formenti[1], Alan Dickin[2]

1. McMaster University, Integrated Science, Class of 2021

2. McMaster University, Professor Emeritus

Received 23 October 2020
Accepted 8 November 2020
Published 4 December 2020

SUMMARY

The geological evolution of the Grenville Province, an area of southeastern Ontario and Quebec, remains a subject of confusion among geologists. Mountain building events have deformed the original features, formed more than 2 billion years ago, making the geology of the area challenging to understand. This study maps the distribution of crustal formation ages within a section of the Grenville Province near the town of Saguenay, Quebec. This provides insight into the crustal provenance of the geological units present, and hence the settings in which they formed. Four geological samples were analyzed to determine the age at which the rocks formed by using the ratio of the radioactive element, neodymium, to its decay product, samarium. The samples analyzed indicate formation approximately 1.5-1.6 billion years ago, which is young in comparison to other portions of the Grenville Province. Mapping the distribution of these ages in conjunction with ages derived from previous studies further constrains geological boundaries within the Grenville Province, delineating the detailed structure of this complicated terrane and the possible settings in which it was formed.

ABSTRACT

The geological evolution of the Grenville Province remains a subject of confusion among geologists. Orogenic events have deformed the original features, making the geology of the area challenging to delineate. This study maps the distribution of crustal formation ages within the Quebecia terrane of the Grenville Province. This provides insight into the crustal provenance of the geological units present. Previous research suggested the presence of slivers of Paleoproterozoic crust (>1.65 Ga) within Pinwarian crust (1.5 Ga). Four geological samples were analyzed from the southern side of the Saguenay graben, where the Paleoproterozoic crustal slivers were thought to extend. Analysis through TDM model ages derived from Sm-Nd radiogenic dating aimed to identify the boundaries of these slivers. Determining the model age distribution within the terrane allows for further delineation of the geological history of the region. The samples analyzed in this study yielded Pinwarian TDM model ages, indicating that slivers of old crust are not present within the study area. These results provide further constraints in the detailed structure of the Quebecia composite arc belt and the geological events preserved within the Grenville Province.

Keywords: Quebecia, model age, accreted arc model, samarium-neodymium dating

INTRODUCTION

Geological Setting

The Grenville geological province is located throughout southeastern Ontario and Quebec, and into the United States, covering over a million square kilometres.[1] Since its formation, the area has been subjected to various mountain building events, known as orogenic events, causing extreme deformation of the original geological units.[1] Among them was the extensive Grenville Orogeny, lasting 1.1 billion years (Ga), that has rendered the geological history of the area extremely challenging to delineate by essentially creating a complicated jigsaw of geological pieces.[1] Previous literature has aimed to determine the geological evolution of the Grenville Province, mainly through reconnaissance sampling and radiogenic dating of rock samples across the area.[1,2] This research has identified sections within the Grenville Province, characterized by geological age and separation by significant geological faults, thrusts and areas of magmatic mixing, as summarized in **Figure 1**.[1,2] In general, the geological units of the Grenville Province, each composed of rock originating from the same geological event with the same lithological properties, decrease in age from the northwestern edge to the southeastern edge.[1]

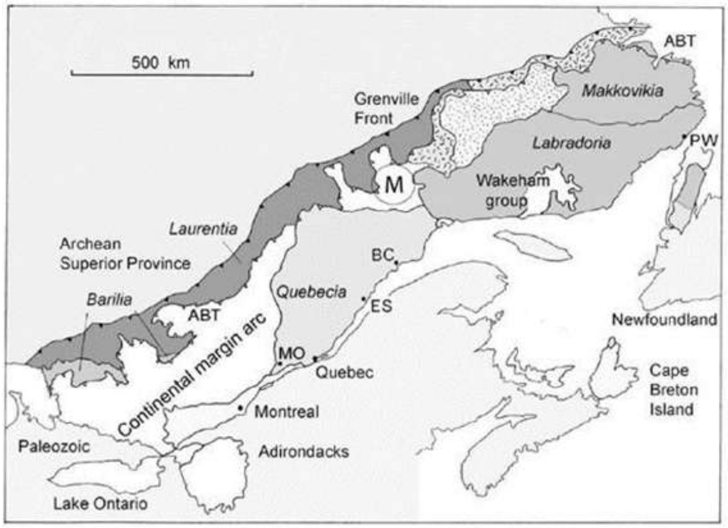

Figure 1. A geological summary map of the Grenville Province and its associated terranes, where M = Manicouagan impact, MO = Montauban, ES = Escoumins, BC = Baie Comeau, PW = Pinware, ABT = Allochthon Boundary Thrust.[3] Obtained from Vautour and Dickin (2019).

One of the most important ways of understanding the geological evolution of the Grenville Province is by using the original age of the crust.[2] Over time and exposure to heat and pressure, such as that brought on by the Grenville Orogeny, rocks are metamorphosed, creating new rocks from preexisting rocks. Determining the original age of the rocks allows geologists to consider the initial processes by which the area formed.[2,4] By defining the ages of the crust, one can identify the timeline of different geological events that formed the region.[4,5] Combining this information with other evidence, including geochemical signatures, lithologies and geological processes pertaining to what is now North America, the geological evolution can be defined.[2]

Previous neodymium (Nd) isotope mapping has defined terranes within the Grenville Province characterized by crustal formation ages.[2] The Quebecia terrane was named and characterized by Dickin (2000) as a Pinwarian-aged terrane with an average crustal formation age of approximately 1.55 Ga.[2] Further research of the current composition of the terrane, with respect to model ages derived from Nd-isotope signatures, aims to reconstruct the geological events that formed this terrane.[3] This paper aims to summarize key literature pertaining to the geological analysis of the Grenville Province, specifically the Quebecia terrane located in the southeastern part of Quebec. In addition, the paper aims to further define the crustal formation ages within Quebecia through the analysis of four crustal samples.

The use of the Nd model ages, derived from the radiogenic decay of Samarium-147 (^{147}Sm) into ^{143}Nd, is a powerful means of determining crustal formation ages of complex geological terranes, in which the original crustal material has been metamorphosed.[4] Empirical models are used to link the composition of the mantle, the source of crustal-forming material, and therefore that of the crust, with approximate ages of extraction from the subsurface. This is possible due to the immobility of rare earth elements (REE) including Nd and Sm.[4] The immobility prevents deviation of the crustal rock sample by post-formation metamorphism and sedimentation events, allowing for the use of a model based on the composition of Earth's mantle from which crust is initially derived.[2,3] This is a key consideration in determining the geological evolution of the crust in the Grenville Province, which has been subjected to various metamorphic events since extraction from the mantle.[1]

The concept of model ages is described by McCulloch and Wasserburg (1978) based on the chondritic uniform reservoir (CHUR) model of DePaolo and Wasserburg (1976).[6,7] These ages are referred to as model ages because they are derived from an empirical model rather than the composition of the mantle.[4] Model ages based on Nd-isotope signatures can be used to describe crustal formation ages by considering the decay of ^{147}Sm into ^{143}Nd with reference to a stable isotope, ^{144}Nd, which remains constant throughout time.[4] As shown in **Figure 2**, the ratio of $^{143}Nd/^{144}Nd$ increases throughout time as ^{147}Sm decays, resulting in a defined relationship between the crustal formation age and the isotope ratio, as indicated by the bulk Earth evolution line.[6]

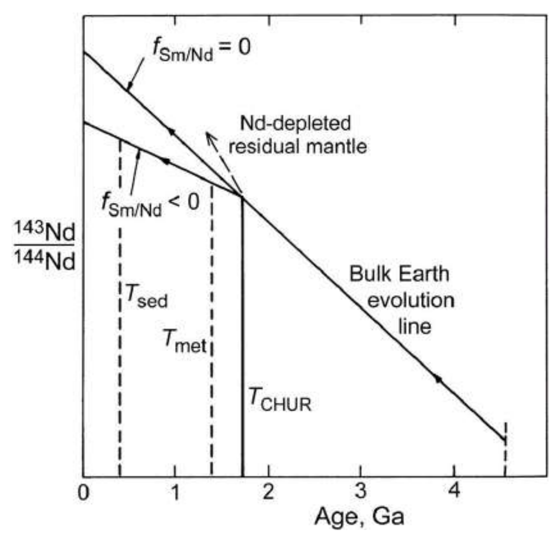

Figure 2. The ratio of $^{143}Nd/^{144}Nd$ increases with time as ^{147}Sm decays to ^{143}Nd. Sedimentary (T_{sed}) and metamorphic (T_{met}) events do not affect this dating method due to the relative immobility of Sm and Nd.[6] Obtained from McCulloch and Wasserburg (1978).

The CHUR model represents the mantle as a uniform reservoir from which crust is formed.[6] A further variable, ϵ_{Nd}, denotes one part per 10 000 that the $^{143}Nd/^{144}Nd$ ratio of a given sample deviates from that of the CHUR model, as calculated by Equation 1. This value is used to describe variation from the empirical model, which can be used in further analysis.[4,7]

(1) $$\epsilon_{Nd} = \left(\frac{(143Nd/144Nd)_{sample\,(t)}}{143Nd/144Nd_{CHUR(t)}} - 1\right) * 10^4$$

The Depleted Mantle Model

In a study by DePaolo (1981), deviation from the CHUR model of samples analyzed from Colorado was noted to be significant and could be represented by a quadratic relationship.[4,7] These data were attributed to the depleted mantle model, which suggests that the mantle, as a reservoir, is in fact not uniform over the geological timescale.[5] This occurs as the mantle is depleted of its crust-forming elements, thereby deviating from the CHUR model which assumes that the reservoir is a closed system throughout the geological timescale.[4,7] Deviation from the model results from incompatible elements, meaning that they are less compatible in melting processes and are depleted from the mantle during crustal formation events at a greater rate than more compatible elements.[4] With respect to determining model ages via the Sm-Nd method, Nd is less compatible than Sm, such that the $^{143}Nd/^{144}Nd$ ratio decreases over time as the mantle is depleted of ^{144}N. This enriches the crust in Nd, and lessens the amount of Nd available in the mantle for future crust-building events.[5] Hence, the CHUR model tends to underestimate the crustal formation age.[4] Instead, crustal formation ages should be calculated relative to the depleted mantle model, producing depleted mantle model ages (TDM), as shown by **Figure 3**.[5]

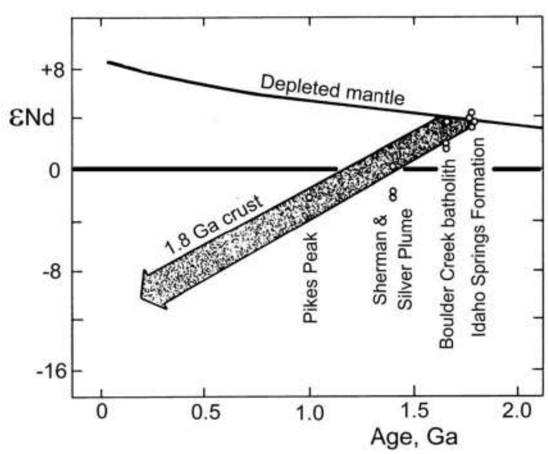

Figure 3. Plot of ϵ_{Nd} values against time from DePaolo (1981) depicting the structure of the depleted mantle model in conjunction with study samples from Colorado, named on the graph.[5] The depleted mantle model, labelled on the graph, is representative of crust forming from a mantle reservoir that changes in composition over time. This deviates from the CHUR model, as represented by the line $\epsilon_{Nd} = 0$.[5,7] The study samples from DePaolo (1981) fall on the large arrow, intersecting the depleted mantle model at an age of 1.8 Ga, indicating the original crustal age of the samples before metamorphism.[5] The left side of the graph denotes present day, in which the depleted mantle model deviates most from the CHUR model, as it is when the mantle has depleted the most.[4] Adapted from DePaolo (1981).

The depleted mantle model is represented by Equation 2, where T is the age in Ga.[5]

(2) $$\epsilon_{Nd}\,(T) = 0.25T^2 - 3T + 8.5$$

This empirical model arguably predicts model ages more accurately as the model accounts for changes in mantle composition over the geological timescale.[5]

The Quebecia Terrane

From a study by Dickin and Higgens (1992), gneisses in central Quebec were identified to have an average age of 1.53 ± 0.07 Ga by means of the Nd-Sm method.[8] The area was interpreted as a relatively homogeneous Mesoproterozoic arc, accreted to the Laurentia terrane, shown in **Figure 1**.[8] Similarly, Dickin (2000) used new Nd-isotope data in combination with previously published and unpublished data to further classify the crustal formation ages and their constraints within the Grenville Province, including those pertaining to Quebecia.[2] These data indicated that the terrane extends from Sept Iles to Trois Rivières, with an average crustal formation age derived from the depleted mantle model of 1.55 Ga.[2] This extends the constraints of the terrane defined in Dickin and Higgens (1992) and is in agreement with the average crustal formation age of the terrane being defined primarily as juvenile Pinwarian.[4,8]

It is notable that analysis of this nature is often paired with uranium-lead (U-Pb) dating methods, which can produce snapshots of absolute rock ages that are not based on an empirical model.[9] U-Pb dates represent a minimum age of crustal formation by dating the age of the most recent igneous crystallization event, rather than the original age of crustal formation.[9] This method is, therefore, less suitable for determining crustal formation ages in the Grenville Province due to post-formational metamorphism events that have since occurred.[9] Nonetheless, U-Pb dates are useful as they can accompany model ages derived from Nd-isotope signatures to validate the accuracy of model ages and further the understanding of the Grenville Province.[5] Comparing model ages to U-Pb ages confirms the accuracy of the depleted mantle model, thereby validating ages. Juvenile rocks that have not undergone metamorphism will have similar U-Pb ages and TDM model ages.[2] This was used by Vautour and Dickin (2019) to demonstrate the homogeneity and juvenile crustal formation ages observed throughout Quebecia.[3] The TDM model ages were suggested to be fairly accurate, as shown in **Table 1**.[3] Furthering the understanding of the Grenville province refers to using U-Pb dating to date magmatic events linked to arc accretion, in which crustal fragments experienced recrystallization. With this, it is notable that the average crustal formation age determined in Dickin (2000) is 100 million years (Ma) younger than the oldest U-Pb ages within the terrane.[2] This is suggestive of metamorphism occurring after crustal formation, possibly as a result of the accretion of Quebecia to Laurentia as U-Pb ages reset with significant melting events.[2]

rentia.[2]

With more in-depth reconnaissance sampling, the homogeneity of the Quebecia terrane was examined, ultimately concluding that Quebecia is far less coherent as a single unit than previously thought.[8] The primary evidence suggesting some aspects of heterogeneity in Quebecia was identified by Dickin and Higgens (1992). Samples with Paleoproterozoic (>1.65 Ga) Sm-Nd isochron ages were found along the Manicouagan River, as shown in **Figure 4**.[8]

Table 1. The oldest U-Pb ages within Quebecia agree, within error, to the average TDM ages presented in Dickin and Higgens (1992) and Dickin (2000), indicating that the Quebecia terrane consists primarily of juvenile Pinwarian-age crust.[2,3,8]

U-Pb Age (Ma)	Source	Age Location	TDM age from Dickin and Higgens (1992) (Ma)	TDM age from Dickin (2000) (Ma)
1506 ± 13	Hebert & van Breemen (2004)	Cap de la Mer amphibolite, Saguenay		
1502 ± 6	Groulier et al. (2018)	Tadoussac granodiorite, Tadoussac	1530 ± 70	1550*
1492 ± 3	Groulier et al. (2018)	Moulin-a-Baude dacitic tuff, Escoumins		

*No error available for data point. Adapted from Vautour and Dickin (2019).

Further evidence from isotope signatures, petrology, trace element geochemistry, and yttrium concentration data from Dickin (2000) establishes the terrane as an oceanic arc accreted to Laurentia.[2] Model ages lie within error of one another throughout sample areas, which is indicative of the terrane being extracted from the mantle in a single crust-forming event.[2] The samples were also found to have more silica-rich and alkali-poor compositions in comparison to other terranes of the Grenville Province. This is consistent with Quebecia having originated from an oceanic crust, which is typically more silica-rich, supporting the theory of Quebecia being an accreted oceanic arc.[2] Finally, yttrium concentrations show similar ranges across the terrane, further indicating homogeneity within Quebecia and adding evidence for an oceanic arc origin.[2] However, it is notable that the northwest margin of the terrane has a large range of Nd isotope signatures, suggesting contamination at the margin by other bodies of crust as a result of accretion to Lau-

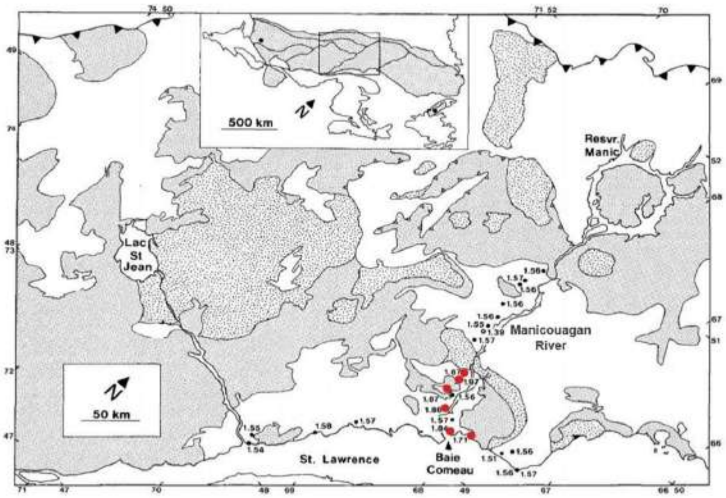

Figure 4. Map of geological units (shown as different textures) from Dickin and Higgens (1992) with Sm-Nd isochron ages of study samples along the Manicouagan River. The red

points denote samples of interest that yielded Paleoproterozoic (>1.65 Ga) crustal formation ages in comparison to the surrounding Pinwarian-aged (~1.5 Ga) crust.[8] Adapted from Dickin and Higgins (1992).

A subsequent study by Vautour (2015) further examined the organization of Quebecia, supporting the complexity of the terrane identified by Dickin and Higgens (1992), and concluded that the terrane should be treated more accurately as a composite arc belt.[10] Nd-isotope signatures examined in this study revealed the presence of older Paleoproterozoic model ages thought to possibly be slivers of older crust that were rifted away from Laurentia.[10]

The slivers of older crust within Quebecia were closely examined by Vautour and Dickin (2019), which defined the extent of two principle slivers referred to as the Labrieville and Loup Marin blocks, as shown in **Figure 5**.[3] The origins of these blocks of older crust are not fully understood, although Vautour and Dickin (2019) suggest the accretion of juvenile oceanic arc crust with attached slivers of Paleoproterozoic crust throughout the terrane.[3]

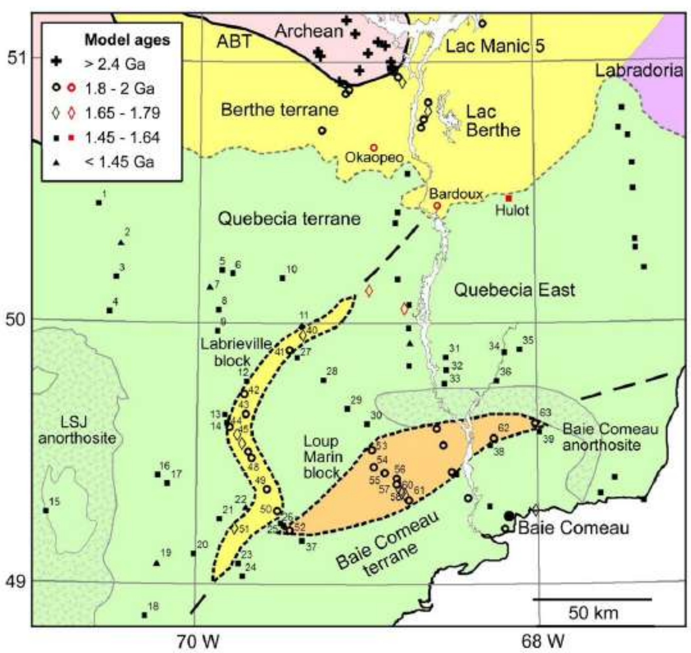

Figure 5. Model ages of the Quebecia terrane from Vautour and Dickin (2019), defining current knowledge on the extent of the Paleoproterozoic Labrieville and Loup Marin blocks within the main Pinwarian crust of the terrane. The Loup Marin block includes the regions of older crust identified in Dickin and Higgens (1992), as shown in Figure 4.[3] Obtained from Vautour and Dickin (2019).

By separating the Quebecia terrane into geological units with respect to model ages from Nd-isotope signatures, it is clear that the terrane is composed of several components.[3,8] This is consistent with it originating from Pinwarian-aged oceanic arcs accreted together with slivers of Paleoproterozoic crust.[3]

The Saguenay Study Area

Prior to this research, evidence for the extension of the main Paleoproterozoic slivers into the study area south of the Saguenay graben was identified in unpublished research by Hynes (2010).[11] This study identified crust with Paleoproterozoic TDM model ages north of the Saguenay river. Combined with previous studies and U-Pb ages, in addition to the extensive deformation characteristic throughout the Grenville Province, the extent and resolution of this section of Paleoproterozoic crust require further investigation.[11] The crust identified in this study could be an extension of the Labrieville or Loup Marin blocks, ultimately being attributed to the composite arc belt model of Vautour (2015) and Vautour and Dickin (2019), which provide an explanation for the heterogeneity throughout Quebecia.[3,10,11]

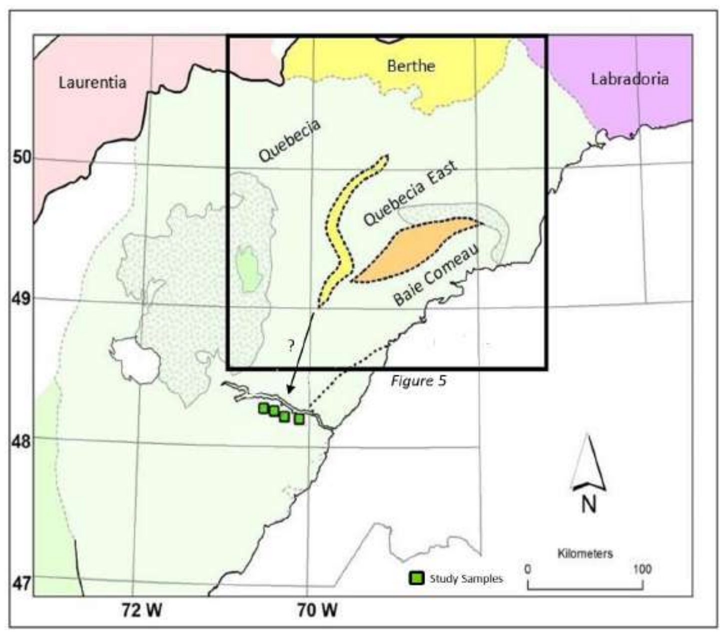

Figure 6. Study samples, shown as green squares, within the dominantly Pinwarian (green) Quebecia terrane. The samples were selected to investigate the possible constraints of the Labrieville (yellow) and Loup Marin (orange) blocks by examining a possible continuation of the blocks, as shown by the black arrow.

METHODS

Four samples were collected from the southern side of the Saguenay graben where the Paleoproterozoic crustal fragments were thought to possibly be present, as shown in **Figure 6**. Samples were selected to be as homogeneous as possible, excluding those with evidence for sedimentary origins. This was done to yield the most suitable crustal formation model ages without mixing from younger mantle components or irrelevant sediments deposited after crustal formation. Rock samples were then prepared and analyzed between October 2019 and March 2020 at McMaster University using the following methods established by Holmden and Dickin (1995).[12]

Rock Crushing

Each sample, approximately one kilogram in size, was broken down in the lab using several pieces of equipment.

Hydraulic Jaw Splitter

A hydraulic jaw splitter allowed for the removal of impurities, including igneous veins and weathered surfaces, to obtain a uniform sample. Another purpose of this step was to form pieces small enough to be put in the jaw crusher.

Jaw Splitter

Small pieces of the sample were placed one at a time inside a jaw crusher, which broke them up into gravel-sized pieces.

Shatterbox

The gravel-sized pieces of the sample were first split into smaller amounts using a table splitter, from which about half of the sample was used. The sample was transferred into a tungsten carbide disk mill which was then placed inside a shatterbox. The first 30 seconds allowed the disk mill to grind the sample into a uniform powder, and the following 60 seconds further fined the powder enough to be dissolved.

Cation and Rare Earth Element (REE) Chromatography

Dissolving and Evaporating

Following being crushed into a fine powder, samples were precisely weighed and recorded before being prepared for analysis. Analysis took place in a clean lab using two different column chromatography procedures outlined below. Rock sample powder was added to a Teflon bomb followed by 1 mL of 3 M nitric acid (HNO_3) and 15 mL of hydrofluoric acid (HF) in order to begin the first step of dissolution. HF solutions were put into Teflon jackets and placed in an oven for four days. After removal from the oven, lids were removed, and solution was evaporated on a hot plate. After evaporation, 7 mL of HNO_3 was added to the bombs and evaporated again on the hot plate. Finally, 6 M HCl was added to the bombs and placed back in the oven.

Splitting and Spiking

Once fully dissolved, samples were diluted with 15 mL of deionized water, shaken, and split by taking approximately 5 mL of sample and transferring it to a smaller bomb, which was spiked using a ^{150}Nd-^{149}Sm solution. Each solution was then evaporated under heat lamps before undergoing separation in cation and REE columns.

Cation Exchange Chromatography

Samples were re-dissolved in 2 mL of 0.3 M HCl and added to test tubes, which were mixed in a centrifuge for 10 minutes. After mixing thoroughly, 1 mL of each sample was loaded onto the cation columns. This was followed by the addition of 1 mL and 2 mL of 3 M HNO_3. Columns were then eluted with 13 mL of HNO_3. Finally, 7 mL of each solution was collected and solutions were evaporated under heat lamps.

REE Chromatography

Samples were diluted with 0.4 M HCl and loaded into the REE columns. Columns were eluted with 1 mL, then 2 mL, and then 7 mL of 0.4 M HCl. Samples with the spike containing Nd were eluted with 12 mL of 0.4 M HCl before being collected, followed by the same columns containing samarium being eluted with 11 mL of 1 M HCl added before being collected. The remaining samples were eluted with 8 mL of 0.4 M HCl before being collected. Finally, the separated samples were evaporated under heat lamps.

Mass Spectrometry

Each sample was split into three solutions, one containing Sm, one containing Nd and the last containing the ratio of $^{143}Nd/^{144}Nd$. Each Teflon bomb containing the final solid was mixed with 80 µL of a dilute phosphoric acid solution and were loaded onto double filament beads for analysis on a VG Isomass 354 Mass Spectrometer. Data collected from each sample can be found in **Table 2**. The resulting TDM model ages were calculated using a computer algorithm and were recorded and uploaded to an ArcGIS map to then be interpreted alongside previous data.

These data were combined with data from previous studies to further define the constraints of Paleoproterozoic crustal slivers within Quebecia using ArcMap.

RESULTS

The samples analyzed in this study yielded results that were consistent with the dominant distribution of Pinwarian-aged crust throughout the Quebecia terrane. The TDM model ages of crustal formation fell between 1.51 and 1.60 Ga, as shown in **Table 2**. In conjunction with previous data, these ages are representative of a juvenile terrane composed of accreted oceanic arcs.

Table 2. Sample data and calculated model ages.

Sample Identification	Y Coordinate (NAD 83)	X Coordinate (NAD 83)	Nd (ppm)	Sm (ppm)	$\frac{^{147}Sm}{^{144}Nd}$	$\frac{^{143}Nd}{^{144}Nd}$	TDM (Ga)
SG42	5339195	417130	7.2	1.15	0.0973	0.511869	1.53
SG44	5341035	404150	24.3	5.17	0.1287	0.512193	1.52
SG47	5345740	395100	82.3	16.47	0.1210	0.512124	1.51
SG48	5348020	385855	14.6	3.00	0.1243	0.512101	1.60

DISCUSSION

Combining these data with previous data further maps the model age signatures within Quebecia. The samples analyzed in this study further defined the extent of the Pinwarian crust, indicating that the Paleoproterozoic slivers do not extend in the study area south of the Saguenay graben. This information is nonetheless important in helping define the constraints of older crustal fragments in order to better understand their origin and the geological evolution of the area. This is seen largely through interpretations of the Labrieville and Loup Marin blocks, shown in **Figure 5**.[3]

It is important to establish that the model age signatures throughout Quebecia indicate that it is an accreted terrane composed of oceanic-derived crust. The sharp boundaries between crustal fragments of different ages are indicative of accretion of different units of crust within Quebecia.[3] Additionally, the fairly elongate Labrieville and Loup Marin blocks, thought to be associated with crustal accretion, are indicative of accretion towards Laurentia in the northwest. Geochemical signatures discussed in Dickin (2000) and Vautour and Dickin (2019) suggest oceanic provenance for the crust of Quebecia.[2,3] The complex geological dispersion throughout Quebecia that lead to the composite arc model is currently explained by theories describing the possible provenance of the Labieville and Loup Marin blocks.[3,10]

One theory suggests the Sumatra region of Southeast Asia, shown in **Figure 7**, as an analogue for the tectonic processes that lead to the formation of Quebecia, describing the complicated assembly of terranes.[3] Sumatra is divided into two elongate terranes, known as Sumatra East and West, which are similar in size to Quebecia and Quebecia East.[3] These terranes are separated by the Medial Sumatra Tectonic Zone (MSTZ), characterized by highly deformed metamorphic rocks thought to be the shear zone along which West Sumatra moved approximately 1000 km westwards relative to East Sumatra. This shear zone can be compared to the Labrieville block that separates Quebecia and Quebecia East.[3]

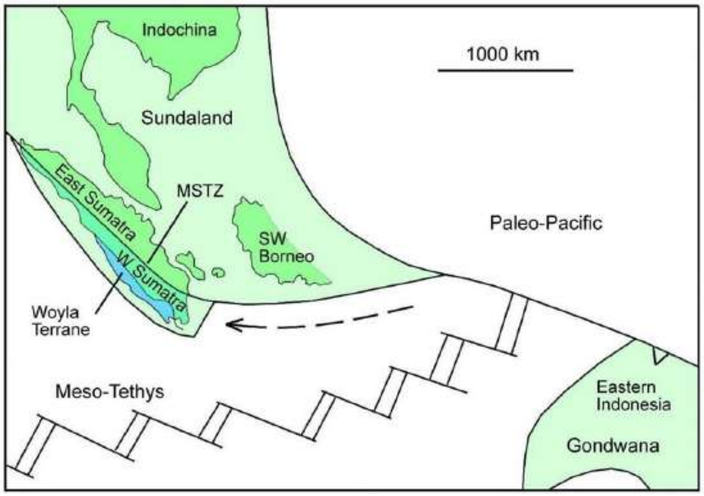

Figure 7. Map showing the westward movement of West Sumatra relative to East Sumatra.[3] Obtained from Vautour and Dickin (2019).

Comparing these two regions, Vautour and Dickin (2019) suggested that Quebecia East can be described as a significantly displaced Pinwarian terrane rifted away from its original location with the attached Labrieville block.[3] Based on this theory, the origin of the Labrieville block should be nearby, within the Grenville Province, as a terrane with a Paleoproterozoic crustal formation age. The geographically nearest terrane with the appropriate crustal formation age is the Berthe terrane, shown in **Figure 6**. With regards to age and location, this is a plausible source for the Labrieville block; however, there is no evidence suggesting that the current positioning of the Labradoria terrane is not approximately the same as it was during the Mesoproterozoic era, making the westward movement of the Labrieville block from the Berthe terrane unlikely given the post-Pinwarian accretion age of Quebecia noted by Dickin (2000).[2,3] Alternatively, the crust could have originated from the Barilia terrane, currently located on the far western side of the Canadian portion of the Grenville Province, as shown in **Figure 1**. This was investigated by Vautour and Dickin (2019) by the plot shown in **Figure 8**.[3] This plot shows the TDM model ages of different units in the Grenville Province alongside the Labrieville and Loup Marin blocks. As seen in the plot, Barilia is the only terrane with similar TDM model ages to the two Paleoproterozoic slivers, suggesting a potential origin. Moreover, the plot indicates that Labradoria has younger TDM model ages compared to the Paleoproterozoic slivers, suggesting they did not originate from Labradoria as previously discussed.[3]

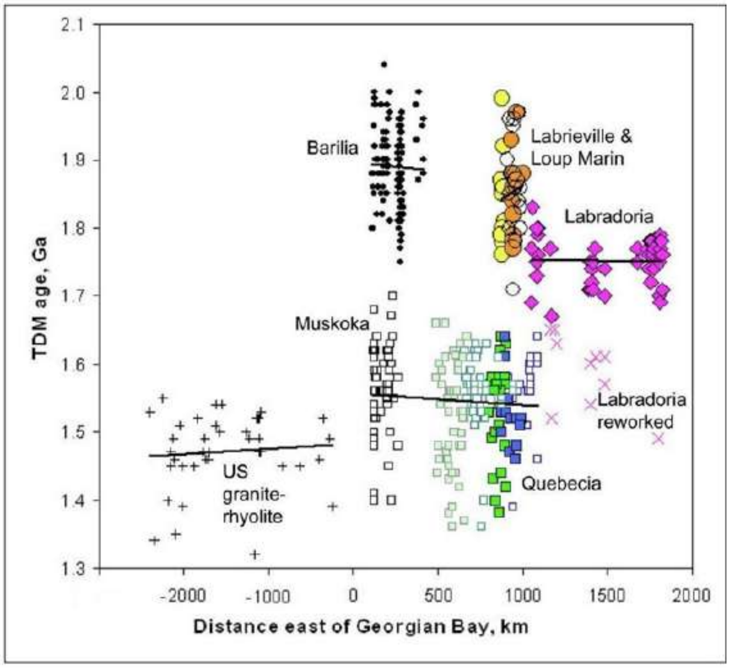

Figure 8. **TDM model ages from various studies plotted with respect to the east-west distance across the Grenville Province**, where black lines represent regressions within certain units.[3] Obtained from Vautour and Dickin (2019).

From this, it is suggested by Vautour and Dickin (2019) that Quebecia East was originally accreted to the far western portion of the continental margin and was later rifted away, eventually moving eastward to its current location in Quebec.[3] Similarly, the Baie Comeau terrane with the attached Loup Marin block, shown in **Figure 5**, was thought to have originated from a similar process in which the younger terrane was attached to the Paleoproterozoic sliver and was rifted away from the source. However, unpublished data discussed in Vautour and Dickin (2019) indicate a significant level of heterogeneity in the Baie Comeau terrane with respect to isotope signatures in comparison to Quebecia and Quebecia East, indicating that the Baie Comeau terrane may have a different provenance.[3] The current suggestion put forth by Vautour and Dickin (2019) is that it is transported eastwards from an ensialic arc to its current location.[3]

CONCLUSION

The literature pertaining to the Quebecia terrane continues to build from previous studies in order to define the geological events, and hence the provenance, of the terrane. Current literature supports Quebecia as a composite arc belt originating from accreted oceanic arcs with attached slivers of Paleoproterozoic crust.[3,10] The terrane can be further divided based on these slivers into three principle blocks termed Quebecia, Quebecia East and the Baie Comeau.[3] Research is required to fully understand the geological history of the area, the origins of Paleoproterozoic slivers of crust within the terrane, and to increase the resolution of the units identified.

These conclusions are drawn from the identification of old model ages along the Manicouagan river by Dickin and Higgens (1992) in addition to the constraints of the terrane investigated by Dickin (2000) and Vautour and Dickin (2019).[2,3,8] Metamorphism resulting from the Grenville Orogeny renders the use of Nd-isotope signatures and model ages useful to estimate crustal formation ages, as identified by Dickin (2000), Groulier et al. (2018) and Vautour and Dickin (2019).[2,3,13] Delineating the geological history of this terrane requires insight into crustal formation ages rather than igneous crystallization ages determined by U-Pb geochronology.[4,9] However, a combination of crustal formation ages from Sm-Nd dating methods and U-Pb ages related to periods of magmatic activity is useful to form a more complete picture of the combination of formation and accretion events recorded within Quebecia.[3,4,9]

The samples analyzed in this study all yielded Pinwarian TDM models ages. This helps to further define the constraints of previously identified Paleoproterozoic crustal slivers within the Quebecia Terrane. The older crust identified in Hynes (2010) was shown to not continue on the south side of the Saguenay river, allowing the current state of knowledge to be improved and the resolution of the TDM model ages in the Saguenay study area to be increased.[11]

Selecting future regions for analysis by similar means is dependent on previously obtained crustal formation ages to identify areas of interest and uncertainty that require further analysis. As the sampling area did not show TDM model ages consistent with the continuation of the Paleoproterozoic slivers, as suggested in

Figure 6, further research could investigate alternative constraints for these blocks, such as that proposed in **Figure 9**.

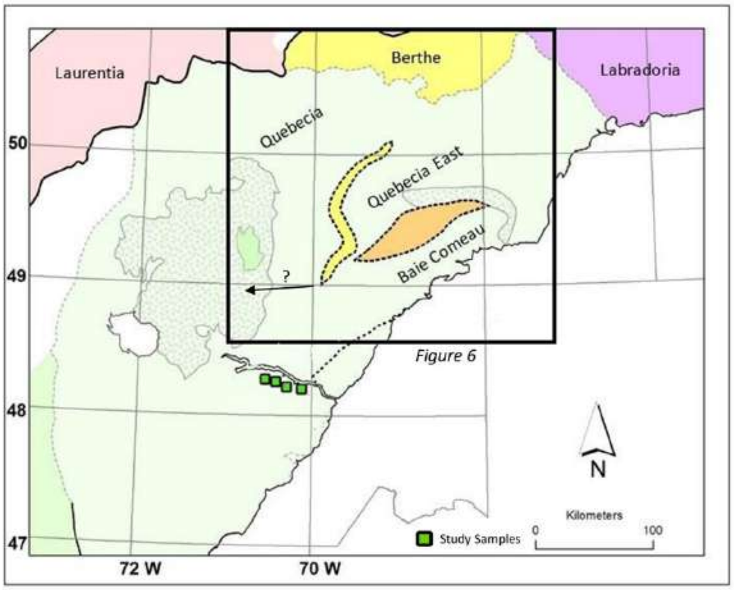

Figure 9. A proposed future study area to further define the constraints of the Labrieville block.

ACKNOWLEDGEMENTS

This project was supervised by Dr. Alan Dickin in the School of Earth, Environment and Society at McMaster University. Thank you to Dr. Dickin for his support, guidance, and patience throughout the project in addition to training and equipment usage in the laboratory. Further support was provided by Dr. Chad Harvey in the School of Interdisciplinary Science who guided the logistical aspects of the project and provided opportunities to share research with my peers. The authors declare no conflicts of interest.

REFERENCES

(1) Rivers T. Lithotectonic elements of the Grenville Province: review and tectonic implications. Precambrian Research. 1997 Dec 22;86(3):117–54.

(2) Dickin AP. Crustal formation in the Grenville Province: Nd-isotope evidence. Can J Earth Sci. 2000 Apr 2;37(2–3):165–81.

(3) Vautour S, Dickin A. Nd isotope mapping of a Pinwarian-age composite arc belt in the Quebecia terrane of the central Grenville Province, Canada. Precambrian Research. 2019 Sep 15;332:105409.

(4) Dickin AP. The Sm-Nd method. In: Radiogenic Isotope Geology. 2nd ed. Cambridge University Press; 2005. p. 70–89.

(5) DePaolo DJ. Neodymium isotopes in the Colorado Front Range and crust–mantle evolution in the Proterozoic. Nature. 1981 May;291(5812):193–6.

(6) McCulloch MT, Wasserburg GJ. Sm-Nd and Rb-Sr Chronology of Continental Crust Formation. Science. 1978;200(4345):1003–11.

(7) DePaolo DJ, Wasserburg GJ. Nd isotopic variations and petrogenetic models - DePaolo - 1976 - Geophysical Research Letters - Wiley Online Library. Geophysical Research Letters. 1976 May;3(5):249–52.

(8) Dickin AP, Higgins MD. Sm/Nd evidence for a major 1.5 Ga crust-forming event in the central Grenville province. Geology. 1992 Jan;20(2):4.

(9) Dickin AP. Lead Isotopes. In: Radiogenic Isotope Geology. 2nd ed. Cambridge University Press; 2005. p. 101–13.

(10) Vautour S. A New Model for the Quebecia Terrane in the Grenville Province As A Composite Arc Belt: Sm-Nd Evidence (MSc Thesis) McMaster University. 2015;66.

(11) Hynes EE. Nd isotope delineation of crustal terranes in the Bancroft area of Ontario and the Saguenay and Baie Comeau regions of central Quebec: Ensialic rifting and arc formation [Internet] [thesis]. 2010 [cited 2020 Apr 6]. Available from: https://macsphere.mcmaster.ca/handle/11375/9020

(12) Holmden C, Dickin A. Paleoproterozoic Crustal History of the Southwestern Grenville Province - Evidence from Nd Isotopic Mapping. Canadian Journal of Earth Sciences. 1995 Apr;32(4):472–85.

(13) Groulier P-A, Indares A, Dunning G, Moukhsil A, Wälle M. Peri-Laurentian, Pinwarian-age oceanic arc crust preserved in the Grenville Province: Insights from the Escoumins supracrustal belt. Precambrian Research. 2018 Jul 1;311:37–64.

ARTICLE INFORMATION

Senior Editor
Stefano A. Biasi

Reviewers and Section Editors
Naomi Suzuki, Keerat Grewal

Formatting and Illustrations
Youssef El-Sayes

ACADEMIC REVIEW OPEN ACCESS

The Value of Manifold Learning Algorithms in Simplifying Complex Datasets for More Efficacious Analysis

Muhammad Amjad[1]

1. McMaster University, Honours Integrated Science, Class of 2023

Received | 1 October 2020
Accepted | 3 November 2020
Published | 4 December 2020

SUMMARY

Suppose you wished to determine the probability of a basketball player scoring a three-point shot. Analyzing previous scoring data would guide you in arriving at a logical prediction. Now, imagine that you aimed to predict the weather. Analyzing previous weather data may not be nearly as useful given that there are an unfathomable number of logged entries that each encompass a multitude of characteristics such as temperature, wind speed, season, etc. An alternative to inefficiently relating data points based on a few overlapping characteristics would be to simply reduce the complexity of the entire set. Rather than predicting the weather based on dozens or hundreds of factors, you would only utilize the few that are the most impactful. This is manifold learning – reducing the complexity of data sets for a more efficient examination. Many algorithms are currently being developed and improved to limit characteristics of data entries, while retaining central information. These simplified entries are graphed on a smooth curve and connected. Points that are crowded will be strongly correlated; hence, illuminating a hidden pattern. This paper will explore the importance of manifold learning in data analysis and its applications.

ABSTRACT

Advances in manifold learning have proven to be of great benefit in reducing the dimensionality of large complex datasets. Elements in an intricate dataset will typically belong in high-dimensional space as the number of individual features or independent variables will be extensive. However, these elements can be integrated into a low-dimensional manifold with well-defined parameters. By constructing a low-dimensional manifold and embedding it into high-dimensional feature space, the dataset can be simplified for easier interpretation. In spite of this elemental dimensionality reduction, the dataset's constituents do not lose any information, but rather filter it with the hopes of elucidating the appropriate knowledge. This paper will explore the importance of this method of data analysis, its applications, and its extensions into topological data analysis.

Keywords: Manifold learning, principal component analysis, Isomap

INTRODUCTION

Significant advances in the field of machine learning can be attributed to the readily available high-quality datasets that are vital for training algorithms.[1] These datasets play an integral role in the development of machine learning algorithms that attempt to predict outcomes. This is done by providing computers with large and complex datasets, from which they can deduce patterns. This knowledge of patterns can be used to predict future outcomes. An instance of predictive modelling is in annual weather prediction. Climatologists and meteorologists train machine learning algorithms with previous weather data to recognize patterns[2]. This knowledge is then used to forecast upcoming weather. This predictive process is both a benefit and a burden. Although large sets of data provide algorithms with a breadth of information, they also hinder their efficiency with irrelevant or misleading details. For example, crowding datasets with unnecessary parameters can lead to issues with clarity. This can make subgrouping, and thus making informed conclusions, difficult.[3] On account of this, mathematicians have developed various techniques in alleviating inessential dimensions in an effort to make machine learning algorithms more efficient. This process is known as dimensionality reduction and is crucial to understand before delving into mathematical modeling of complex data.[4]

Dimensionality reduction aims to simplify datasets with the hopes of making them more efficient for machine learning algorithms. Dimensionality reduction can assist with scientific understanding by visualizing complex data. For example, if a dataset consists of 50 dimensions, then there are 50 attributes categorizing each individual point within that collection. This makes the process of finding meaningful relationships very challenging as a great deal of irrelevant information must be filtered first. This irrelevant information is sometimes referred to as noise, large amounts of additional or meaningless information.[5] If a dimensionality reduction algorithm could be used to convert 50 dimensions into 3, then it would expedite the process of visualizing connections between data points. Apart from visualization, dimensionality reduction may also assist in elucidating underlying forces behind complex datasets. For example, dimensionality reduction can be used to improve the geophysical log data that classifies crystalline rocks.[6] Log functions are used to classify rock types after the machines measure their characteristics, such as surface area, density, porosity, etc. However, many of these log functions may not be of use as several different types of rocks have overlapping characteristics. Shale and claystone, for example, are very similar in grain size.[7] Using log functions that include similar characteristics, such as grain size, when differentiating between shale and claystone would be redundant. With the use of dimensionality reduction algorithms, reduced-log sets that are the most important to the classification process can be used instead. Furthermore, providing feedback to the original algorithm can extend the capabilities of this technique. Machine learning will allow the algorithm to optimize itself by learning from the instances in which it was correct or mistaken.[8] This will allow it to make more statistically advantageous decisions and prioritize what reduced-log functions should be provided to the geological machinery. This instance of dimensionality reduction in machine learning algorithms exemplifies the importance of simplified datasets.

The simplification of large datasets by dimensionality reduction serves to remove repetitive and overlapping information. Take, for example, a large dataset that is governed by 100 dimensions. Given the number of parameters, there is bound to be overlap in the data points. It is possible that out of 10,000 elements, 1,000 will mirror the same behaviour along 15 dimensions. If the goal is to find relationships between data points, then continuous overlapping between parameters will not show any real connection. This is an inherent inefficiency in the machine learning system and can be undone by extracting the integral parameters and excluding derivatives of the same dimensions.[9] It is important to note that reducing the dimensions does not inherently limit the data itself. Suppose there is a large data set of one million participants and one hundred dimensions that indicate character traits. If the dimensions are reduced to three traits, such as integrity, honesty, and responsibility, 97 dimensions still remain for each data point. However, the additional 97 dimensions are virtually emphasized because the system only visualizes relationships between participants for the three traits. Furthermore, there could possibly be infinite dimensions to the dataset, but only one hundred were selected initially, and three left after the reduction. Therefore, the potential classification of the dataset is not bound by the three dimensions set by the algorithm. This high-dimensional space that the data could belong to is known as the feature space.[10] The low-dimensional space that the algorithm reduces the dataset to reflects the applied parameters. The manifold structure that will soon be created will import aspects of both high and low-dimensional space, and will find meaningful relationships from large sets of data.

NOTATION

- The high-dimensional points will be sectioned in matrix X, where the i^{th} row is x_i $(x_1, x_2, \dots, x_n)$. Here, n is the number of points in the dataset and can vary widely. Similarly, the low-dimensional parameters will be $y_1, y_2, \dots, y_n$ within the matrix Y.[11]
- D is denoted as the dimensionality of the dataset before the reduction algorithm is applied, located in R^D space. Resultantly, d is the dimensionality of the deriving manifold.[12]
- (v_i, λ_i) are eigenvector-eigenvalue pairs for $i = 1, \dots, n$. From this $\lambda_1 \geq \lambda_2 \geq \dots \geq \lambda_n$. If $v_1, \dots, v_d$ are the d eigenvectors in high-dimensional space, then $v_{n-d+1}, \dots, v_n$ represent the low-dimensional d eigenvectors. The eigenvectors will change due to the reduced dimensionality of data. The notion of eigenvectors will be elaborated on in the preliminaries section.[13]
- k is the number of nearest neighbors while $N(i)$ is the set of k-nearest neighbors of x_i. This algorithmic concept will be discussed in the preliminaries section.[14]

PRELIMINARY MATHEMATICAL KNOWLEDGE

Eigenvectors are a set of vectors associated with a linear system of equations, such as the ones found in the matrix X and Y established previously.[15] Each of these eigenvectors will have a corresponding eigenvalue. If (v, λ) is an eigenvector-eigenvalue pair of space R, then for any i, (v_i, λ) is an eigenvector-eigenvalue pair of R^i. Similarly, for any k, (kv, λ) is an eigenvector-eigenvalue pair of kR.

The K-nearest neighbors (KNN) algorithm is widely used in pattern recognition and machine learning.[16] It is an example of a supervised machine learning algorithm, which relies on labeled input data to learn and then produce an appropriate output when given new unlabeled data. These algorithms can be used to solve classification or regression problems. KNN assumes that data points with similar characteristics will reside close to one another on a visual plane, such as a manifold structure. Initializing a *k-value* will find the data points closest to a selected starting point. For example, if k is initialized to $k = 3$ and the first data point is defined as $x = 1$, then the algorithm will find the three most similar data points to the *x-value*. Ultimately, the algorithm will find the desired points by taking the shortest distance between the initialized value and the other values within the dataset. For this example, the three shortest distances will exemplify the three nearest neighbors and those will be outputted. This algorithm proves versatile for classifying the similarities and differences within a dataset.

LINEAR DIMENSIONALITY REDUCTION

Principal Component Analysis (PCA) is a technique for reducing the dimensionality of large datasets while maximizing interpretability and minimizing information loss.[17] Suppose there is a dataset with points that share similar characteristics. These points belong in the same dimensions, but are still unique in their own respects. If the number of characteristics (dimensions) were reduced, then the uniqueness of each point could be more easily observed and quantified. From this, comparisons can be made between each data point along specific parameters to better understand their similarities and differences. For instance, suppose there are three biological cells that each share a common gene;[18] however, the percentage of their genome that consists of that gene is different. If that percentage is the underlying parameter, then each cell can be compared to the other to determine relative similarity (i.e. cell 1-to-cell 2, cell 2-to-cell 3, and so on). This will elucidate which cells are most similar with respect to that specific dimension, yielding several correlational observations amongst samples in the dataset. However, if the number of cells increases linearly, then the number of possible combinations will increase exponentially. This will become increasingly repetitive and inefficient in the long run with large datasets. Instead, a PCA plot is constructed, which will convert the correlations, or lack thereof, among all the cells into a 2-D graph. Cells that are highly correlated will cluster together given that they share very similar characteristics. Perhaps if some cells are very similar in specific characteristics, they will even overlap. These overlapping clusters are exceptionally valuable as they demonstrate great similarity with respect to the dimensionality of the PCA plot. Limited dimensionality overlap provides a comprehensive outlook on how some points react to only a few parameters, which can then be explored further. Once the clusters are identified, the cells contained within can be examined individually to study why correlations were detected by the algorithm. This method is not exclusive to cells and can be applied to any large dataset that needs to be refined by specific dimensions. It is also important to note that the relative distances between clusters is significant. If a specific dimension is prioritized, then clusters spread out along the axes of that dimension will not be as closely correlated because their values will differ greatly. PCA algorithms can be checked for accuracy by initializing them with training data, then providing them with new test data to see if they sort in a similar fashion.[19] It is critical that variance is minimized between similar data points, but maximized for dissimilar ones.[20] Essentially, it is ideal to have tightly packed clusters that are spaced out along the linear subspace. This will be beneficial when grouping data that is similar and separating sets that are not. PCA will render a dataset devoid of any irrelevant features, as no extraneous dimensions will be included by the algorithm. A sample PCA plot that compares three species of *Iris* plants is illustrated in **Figure 1**.

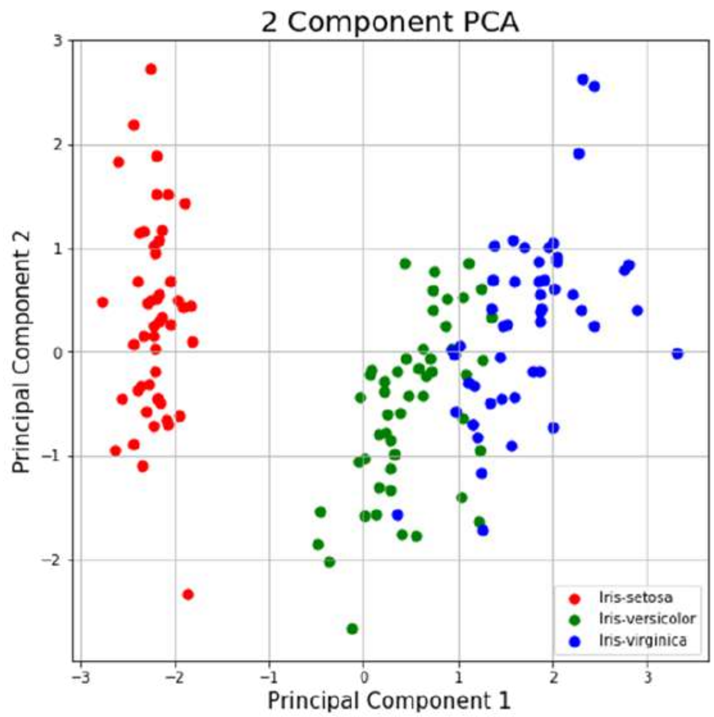

Figure 1. Python was used to perform PCA for three different species of *Iris* plants. Axes of similarities were growth habits and bloom times (arbitrary units). *Iris versicolor* and *Iris virginica* appear to be similar with respect to parameters as they clustered, while *Iris setosa* is different from the other two (see Appendix A).

In order to model the manifold structure, it is important to first develop a maximum variance equation that will segregate unrelated elements in a dataset. Suppose that the matrix $X \varepsilon R^{nxD}$ has rows, which are D-dimensional data points. Along this space of R^D, there must be a linear subspace where the provided dataset has a maximum variance.[21,22]

$$var(XV) \qquad \textbf{Eq. 1}$$

where V is an orthogonal $D \times d$ matrix. If $d = 1$, then there is simply a unit-length vector as the orthogonal matrix will be composed of only one column. This is ideal for constructing the objective equation, as direction of the maximum variation will be given by the unit vector which contains the projected data points.

$$var(Xv) = E(Xv)^2 - (EXv)^2 \qquad \textbf{Eq. 2}$$

To simplify this equation, the dataset can be assumed to be mean-centered, which will eliminate the sum of the vectors within the one-column matrix. This can be seen as a possible limitation of the method, as the process of maximizing variance becomes increasingly more complex as more elements are added to the vector.

$$var(Xv) = E(Xv)^2 \qquad \textbf{Eq. 3}$$

Note that $E(Xv)$ is the sum of all $x_i v$. Given that V is an orthogonal matrix, the transpose must be taken for X , making the equation $x_i^T v$ [14].

$$var(Xv) = \sum_i (x_i^T v)^2 \qquad \textbf{Eq. 4}$$

In order to conduct matrix multiplication for Equation 4's squared terms, the transpose of the terms must be used.[14] This transpose method is the result of multiplying two vectors.

$$var(Xv) = \sum_i (v^T x_i)(x_i^T v) \qquad \textbf{Eq. 5}$$

$$var(Xv) = v^T \left(\sum_i (x_i x_i^T) \right) v \qquad \textbf{Eq. 6}$$

Equation 6 must be further maximized by setting v to the largest corresponding eigenvector, as seen in Equation 7. This will yield a manifold curve that is embedded in high-dimensional space, while being low-dimensional itself. This removes the sum component and leaves the X matrix, the orthogonal matrix, and their v respective transposes.

$$var(Xv) = v^T X^T X v \qquad \textbf{Eq. 7}$$

MANIFOLDS

This section will focus on the characteristics of a manifold, as well as the ways in which the structure relates to general topology and geometry. As mentioned previously, the goal of this exploration is to obtain a manifold whose parameters lie in low-dimensions while the actual data points are high-dimensional. It is important to remember that the feature space is R^D and the reduced space is R^d. Hence, D will be larger than d as its dimensionality has not been reduced. This distinction and notation are important to remember before the concepts of homeomorphism can be discussed.

Homeomorphism is a method of deformation that is unique to the study of topological structures. A homeomorphism is a continuous function between topological spaces that also has a continuous inverse function.[23] In the field of topology, functions can be characterized as objects. If two objects are homeomorphic, they can be deformed into each other by continuous and invertible mapping.[23] To better visualize this concept, imagine a donut made of clay. This donut can be morphed into the shape of a coffee cup by moulding the surfaces, and without cutting or adding any new clay. These two objects are topologically equivalent. A manifold is a topological space that resembles that of Euclidean space, but only locally.[22] For the purposes of this exploration, visualize Euclidean space as a standard coordinate axis, much like the x-axis on the cartesian plane. That is to say, the vicinity of each point can have a coordinate axis which behaves Euclidean, but may not be. For instance, the surface of a sphere is a manifold. For any point on the surface of the sphere, there can exist a local coordinate system. However, that number line will only be valid for a small section as movement away from that section of the surface will change the angle and thus the straight coordinate system will fail to be of use. On account of this, manifolds are locally homeomorphic to Euclidean space. Mathematically, a *d-dimensional* manifold M is locally homeomorphic with R^d. The local section of a manifold can be labeled as neighborhood N_x for each $x \varepsilon M$, given that each neighborhood is locally homeomorphic with Euclidean space, $f: N_x \rightarrow R^d$. The process of integrating a manifold M in a section of R^d space is known as embedding.[24] Understanding the topology and geometry behind manifolds will allow for its accurate algorithmic implementation.

MANIFOLD LEARNING

This section will discuss how algorithms will learn from manifolds that are constructed with complex datasets. Suppose there is a data set $x_1, \ldots, x_n \varepsilon R^D$ and its dimensionality needs to be reduced for it to be interpreted conclusively. PCA would not work in this case as the data does not lie on a low-dimensional subspace of R^D. Trying to apply PCA would take far too long and be an inefficient use of resources as multiple trial combinations between data points would need to be generated. Instead, the dataset should be interpreted as lying on a *d-dimensional* manifold embedded in R^D.[25] As previously mentioned, d must be a great deal smaller than D for dimensionality reduction to occur. For simplicity, it will be assumed that the manifold is only two -dimensional. This would yield a single coordinate system. The manifold M can be constructed from dataset $x_1, \ldots, x_n \varepsilon R^D$ in a single coordinate system $f: N_x \rightarrow R^d$ as a result of $y_1, \ldots, y_n \varepsilon R^d$, where $y_i = f(x_i)$.[26] An algorithm will learn to assemble a manifold from a dataset through this process, hence, manifold learning. An example of a simple manifold resulting from a training dataset is the surface curve. This curve is a two-dimensional manifold in three-dimensional space. This is topologically identical to that of a sphere, where the surface can be homeomorphic to an S-shaped curve. The curve has length and width, which makes it two-dimensional, but it resides in three-dimensions. That same curve can stretch to a variety of different objects in order to demonstrate the homeomorphic qualities of the structures. The concept of homeomorphism between these topological structures is important because plotted datasets can yield unpredictable shapes, such as a sphere. Homeomorphism demonstrates that the visualizations can be morphed to simplify the relationships, thus deriving meaning from complex data. The ability for a computer to learn a manifold from a set of points proves to be intricate and cerebral, and has countless applications when utilizing a range of datasets.

ISOMAP AND MULTIDIMENSIONAL SCALING

Isomap is a nonlinear dimensionality reduction method, which makes it ideal for the modeling of a manifold by embedding the dataset's information into Euclidean space. Specifically, Isomap computes a quasi-isometric and low-dimensional structure by embedding sets of high-dimensional data points.[27] Quasi-isometry refers to a large-scale geometrical figure's function that ignores the small-scale details. This allows for the easy estimation of a structure's intrinsic geometry based on a rough estimate of each data point's neighbors.[28] Recall that in order to find a data point's similarities with other inputs, it must be grouped with those inputs along a low-dimensional plane. Isomap will employ KNN, which will allow for the algorithm to find the points that are closest to each other, and hence, the most similar in characteristics relative to the parameterized axes. Points that are closest together in the KNN algorithm will then be grouped together in the final manifold. In order to embed the necessary dataset into a manifold, a multidimensional scaling (MDS) algorithm must first be utilized.[29] This is similar to Isomap, where information is visualized by displaying the contents in a distance matrix. Displaying the elements of a matrix along a set of axes will sort the information into groups that are similar, thereby elucidating patterns amongst the dataset. This is another method of nonlinear dimensionality reduction. The importance of MDS is to find interpoint distances in the visualized dataset.[30] Essentially, interpoint distances refers to the distance between two points randomly chosen on a plot. For this exploration, the points will be randomly chosen within a similar cluster, as these points are similar with respect to the parameters. This is done to yield MDS interpoint distances that are similar, if not identical, to the KNN distances in the Isomap method. Isomap will synthesize a manifold and construct lines between the points, while MDS will find the distances between these points. MDS can only be used locally as it uses Euclidean geometry, which is a local coordinate system. As the manifold curves with the addition of more data points, the MDS will not work for comparing data points that are further apart. Hence, MDS can only be used to get distances of neighboring points after Isomap has constructed the manifold. **Figure 2** showcases an example of MDS comparing the presence of two metagenomes in five different pig organs. Greater distances between data points correlates to more significant differences with respect to the metagenomic presence. Ultimately, both methods will prove fruitful in the exploration to generate a topological manifold from a large dataset.

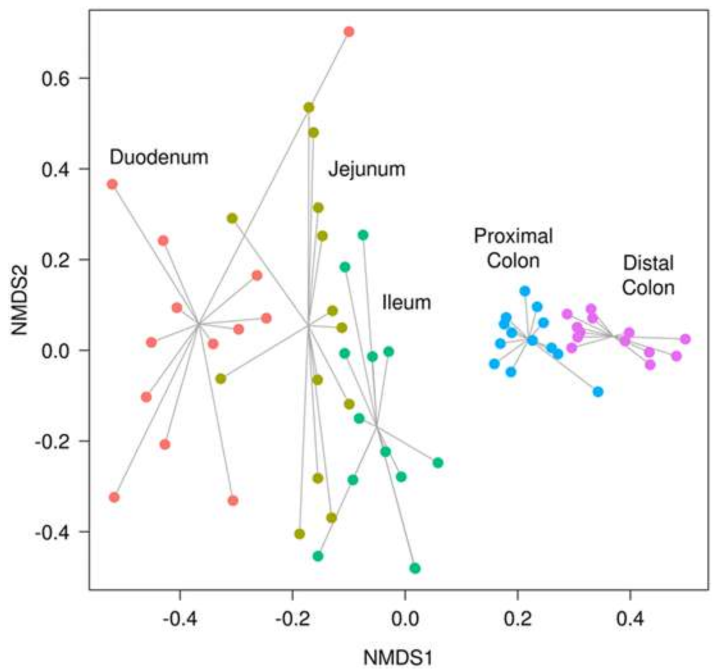

Figure 2. Example of MDS used to plot dissimilarities for two arbitrary metagenomes in five different intestinal sections of a pig. This plot showcases the genomic presence of each metagenome in the different sections. Points clustered together are similar in their metagenomic composition for the two chosen genomes. Interpoint distances are taken between each point and that organ section's average NMDS1 and NMDS2 value. Interpoint distance illustrates how deviated a point is from the other samples in the same section.[31]

Taking distances between adjacent points can be done using Isomap and MDS as the generated distances will be relatively small. However, data points that are further apart will be more difficult as MDS only takes Euclidean distances, which cannot be done between data points that are on different curved sections of a manifold. Instead, distances between points on a manifold must be taken. To better visualize this, imagine two points on a sphere that are far apart. The distance between these points cannot be calculated, because it would involve passing through the sphere to get the shortest length. Instead, the distance must be taken while still traveling along the surface of the sphere. This will involve tracing from point A to point Z. A computer can do this by taking the distance from point A to some point B that is closer to point Z and also close enough to point A, so that taking the distance does not involve passing through the curved surface of the sphere. Then, the distance between point B and some other point C can be taken, and that distance will add to the previously mentioned distance. Continuously, points will be selected that are separating point A and point Z, until a distance is obtained between the two points far apart. This is known as Dijkstra's algorithm.[32]. This algorithm can be applied to this exploration to construct a manifold. For data points that are far apart, smaller distances between those points can be calculated and then added to yield the cumulative distance. Having MDS calculate local distances and Dijkstra's algorithm quantify larger distances will allow for the construction of a manifold that contains all data points.

Dijkstra's algorithm can be mathematically expressed, and then implemented into the Isomap and MDS algorithm. If x_i, x_j are points on the manifold and $G(x_i, x_j)$ is the distance between them, then there is a chart $f : M \to R^d$, such that $\|f(x_i) - f(x_j)\| = G(x_i, x_j)$.[33] In this equation, the short distances across high-dimensional Euclidean space will be calculated from neighboring points. This equation will not prove useful however, for distances that stretch far across the manifold structure. This is, again, due to the fact that the manifold is locally linear, and the equation will have to map through paths that have already been delineated. Instead, Dijkstra's algorithm can be used to estimate the distance from one point to another using the preexisting distances connecting each adjacent point[34]. This will estimate the distances between distant points, which will accompany the information already approximated from the aforementioned equation. Now that Isomap has been utilized, MDS can be put into effect. Recall that MDS will calculate interpoint distances that correspond to the KNN distances calculated using Isomap. In order to use MDS, the calculated Euclidean distances will need to be converted to a Gramian matrix. A Gramian matrix consists of all possible inner products of another matrix.[35] In this particular problem, the starting matrix is $D \in R^{nxn}$. If X is the matrix of D that is needed, then B is the Gramian matrix; $B = XX^T$, where X is found through spectral decomposition of B into $U\Lambda U^T$.[36] This will yield $X = U\Lambda^{1/2}$. From here, PCA will again be employed to project X onto d-dimensions given that there is a desire to keep the data embedded in a low-dimensional manifold. This will yield XV, where $V \in R^{nxd}$ is the original matrix containing the dataset. Here, the rows are eigenvalues while the columns are eigenvectors. These eigenvectors $v_1, \ldots, v_d$ are provided by

$$X^T X_{v_i} \qquad \textbf{Eq. 8}$$

Substitute the structural decomposition formula mentioned above into Equation 8 and expand terms of matrix and its transpose to simplify.

$$\left(U\Lambda^{\frac{1}{2}}\right)^T \left(U\Lambda^{\frac{1}{2}}\right) v_i \qquad \textbf{Eq. 9}$$

$$(\Lambda^{\frac{1}{2}} U^T U \Lambda^{\frac{1}{2}}) v_i \qquad \textbf{Eq. 10}$$

$$\Lambda v_i \qquad \textbf{Eq. 11}$$

when $v_i = e_i$, e_i is the i^{th} standard basis vector. Hence, $XV = X[e_1 \ldots e_d] = [X]^{nxd}$. Although this seems quite syntactical and complex, it signifies that the dimensionality of the subspace in which the manifold lies is exactly where the matrix X lies. Hence, MDS can be used to find the dimensionality of the manifold space. However, this method of MDS is limited in its capabilities since D's distances are merely an approximation. If the approximation deviates from Isomap's approximations too greatly, this will prevent the formation of the Gramian matrix. Improving the algorithm to accommodate for this mistake can serve as a future extension to this exploration. From these calculations, the distances between data points on a manifold will be approximated, which will prove useful when interpreting the relationship between the dataset's elements. **Figure 3** is a plot of both Isomap, and MDS that utilizes the Dijkstra algorithm. This gives **Figure 3** the capability to construct a three-dimensional manifold with similar points being close together.

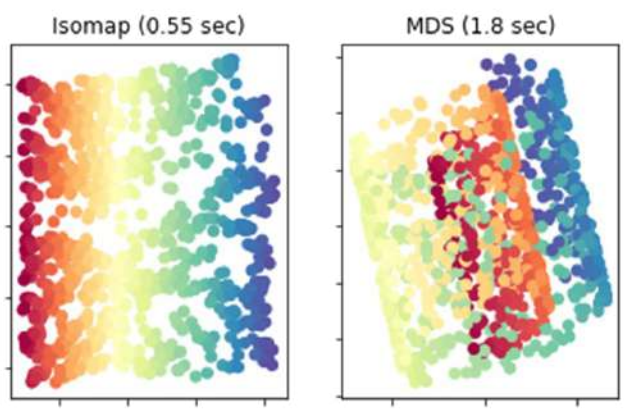

Figure 3. A sample plot of 1000 points reduced to three dimensions of x, y, and z in both Isomap and MDS with computer generation time displayed. Points consist of arbitrary values in three-dimensions in range of figure size. Isomap is the manifold containing all data points while MDS views it from a different angle to capture its depth. Points that are close together are similar with respect to the arbi-

trary parameters of this database plot. Similar/local points are highlighted in similar colours for easy identification of their shared characteristics (see Appendix B).

APPLICATIONS

Isomap and MDS are incredible tools to use in the modeling of manifolds from large and complex datasets. The Isomap effectively reduces the dimensionality of the provided datasets, which allows the manifold to be derived with ease. Nevertheless, this process is not perfect. These algorithms attempt to reduce dimensionality in order to limit the noise in the dataset while maintaining relevant parameters. As a way to prevent losing all vital information, the algorithm may be "generous" in the sense that not all parameters that are deemed irrelevant are removed. Ultimately, some inapt information will be included in the final model, so the process is not entirely efficient. An advantage to using Isomap over MDS is the time difference. Isomap typically takes less than half the time of MDS, which is advantageous for widespread future applications where computers are expected to quickly find relationships in large-scale datasets.[37] For instance, suppose military personnel wanted to find the exact location of a specific target from voice data.[38] Isomap would be ideal for this situation as it is relatively fast and would segregate the audio samples based on similar characteristics, such as languages and speech patterns. This could then be cross-referenced with collected audio from nearby transponders and ultimately assist the military in triangulating the target location.[38] In different circumstances, MDS may be ideal when analyzing voting data and predicting the outcome of elections.[39,40] An MDS algorithm could construct a visualization of voters by parameterizing their voting history. This would work to segregate groups with similar interests. Those that are grouped closely together with small neighboring distances will likely vote in a similar fashion. This can be useful in determining which groups are firm in their position and others who are relatively lenient based on their relative position along the axes. From this, electoral voting campaigns can target specific demographics that are elucidated from this process.[41] These are merely a few applications of manifold learning, an incredible tool that will likely see tremendous growth in research-oriented fields.

LIMITATIONS

A number of limitations occurred throughout this literature review, all of which were a result of the manifold learning method. As mentioned in the Isomap and multidimensional scaling section, the Isomap and MDS distances cannot deviate too much from one another, or else a Gramian matrix will not form. This was conclusive across all papers, but was rather vague and unexplained, leading to more questions. The Jupyter Notebook simulations in **Figure 3** were created using an open source dataset, but it is questionable what the output would have been if the KNN and MDS distances did not correspond. The cited literature also did not make note of this dilemma, or how it could be resolved. Additionally, the papers discussed that the KNN and MDS values can only deviate slightly to yield an adequate Gramian matrix. This is yet again a vague phrase that begs an explanation. What amount or percent can the results of the two methods deviate in order to still yield a functioning Gramian matrix? In order to improve the algorithm for future use, and combat the dilemma of different KNN and MDS distances, a thorough understanding of the underlying causes must be explored. An additional limitation that arose during this exploration concerned the foundational concept of dimensionality reduction. Many papers noted that computers will reduce dimensions somewhat sparingly to avoid the loss of vital information. Not all parameters that are deemed irrelevant are removed. This is simple, but rather vague from the perspective of programming. How do algorithms rank irrelevant pieces of information to preserve knowledge from the dataset? Quantifying the ideas behind this concept would be beneficial to further understand the nuances of the manifold learning algorithm. Moreover, it would be favourable to provide information on the handling of irrelevant information before it is integrated into the final model. Addressing these vagaries would significantly improve ideas around this concept. Although there are some limitations in this literature review, the general concepts of manifold learning were easily understood and appear to be extraordinary in their future implications.

CONCLUSION

This exploration on manifold learning has proved to be advantageous as it works to untangle the complexities behind geometric interpretations of data, while illuminating the benefits that the procedure can provide to data analytics. Though manifold learning has become an increasingly popular area of study within machine learning, much is still unknown. This paper explored only two methodologies of manifold learning: Isomap and multidimensional scaling. This is not an exhaustive list as many more exist, and continue to develop. Testing a multitude of algorithms may provide different perspectives and results, which would improve scientific understanding in this area of discipline. Utilizing more real-world data sets would also be of great benefit. It is important to train algorithms to determine whether they provide sensible outcomes, but real-world data should also be used to test if the methodologies can have widespread applications. Perhaps most real-world datasets do not lie along an embedded manifold. Realizing this now and adjusting the development of these algorithms would be the best option. Manifold learning as a methodology proves to be a promising resource in elucidating meaningful relationships from otherwise complex datasets.

ACKNOWLEDGEMENTS

This paper and the research behind it would not have been possible without the exceptional support of my mentor, Khawar Zaidi. His enthusiasm, knowledge and exacting attention to detail have been an inspiration and kept my work on track from my first encounter with the concepts of manifolds, to the final draft of this paper. I am also grateful for the insightful comments offered by my colleagues in the Bachelor of Integrated Science program at McMaster University. The authors report no conflicts of interest.

REFERENCES

(1) Jackson Q, Landgrebe D. An adaptive classifier design for high-dimensional data analysis with a limited training data set. IEEE Transactions on Geoscience and Remote Sensing. 2001;39(12):2664–79.

(2) Rasouli K, Hsieh WW, Cannon AJ. Daily streamflow forecasting by machine learning methods with weather and climate inputs. Journal of Hydrology. 2012;414-415:284–93.

(3) Saunders B, Sim J, Kingstone T, Baker S, Waterfield J, Bartlam B, et al. Saturation in qualitative research: exploring its conceptualization and operationalization. Quality & Quantity. 2017;52(4):1893–907.

(4) Roweis ST. Nonlinear dimensionality reduction by locally linear embedding. Science. 2000;290(5500):2323–6.

(5) Yang J, Peng W, Ward M, Rundensteiner E. Interactive hierarchical dimension ordering, spacing and filtering for exploration of high dimensional datasets. IEEE Symposium on Information Visualization 2003 (IEEE Cat No03TH8714). 2003.

(6) Konaté AA, Pan H, Ma H, Cao X, Ziggah YY, Oloo M, et al. Application of dimensionality reduction technique to improve geophysical log data classification performance in crystalline rocks. Journal of Petroleum Science and Engineering. 2015;133:633–45.

(7) Folk RL. The Distinction between Grain Size and Mineral Composition in Sedimentary-Rock Nomenclature. The Journal of Geology. 1954Jul;62(4):344–59.

(8) Zemzem W, Tagina M. Cooperative multi-agent systems using distributed reinforcement learning techniques. Procedia Computer Science. 2018;126:517–26.

(9) Kuwana T. Repetition advantage and disadvantage in perceptual identification tasks. Japanese Psychological Research. 2012;55(3):216–28.

(10) Pang Y, Yuan Y, Li X. Effective feature extraction in high-dimensional space. IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics). 2008;38(6):1652–6.

(11) Fan J, Fan Y, Lv J. High dimensional covariance matrix estimation using a factor model. Journal of Econometrics. 2008;147(1):186–97.

(12) Vlachos M, Domeniconi C, Gunopulos D, Kollios G, Koudas N. Non-linear dimensionality reduction techniques for classification and visualization. Proceedings of the eighth ACM SIGKDD international conference on Knowledge discovery and data mining - KDD '02. 2002.

(13) Talwalkar A, Kumar S, Mohri M, Rowley H. Large-scale manifold learning. Manifold Learning Theory and Applications. 2011;:121–43.

(14) Han H, Mao B. Fuzzy-rough k-nearest neighbor algorithm for imbalanced data sets learning. 2010 Seventh International Conference on Fuzzy Systems and Knowledge Discovery. 2010.

(15) Powers DL. Graph partitioning by eigenvectors. Linear Algebra and its Applications. 1988;101:121–33.

(16) Sarkar M. Fuzzy-rough nearest neighbor algorithms in classification. Fuzzy Sets and Systems. 2007;158(19):2134-2152.

(17) Abdi H, Williams L. Principal component analysis. Wiley Interdisciplinary Reviews: Computational Statistics. 2010;2(4):433-459.

(18) Pierson E, Yau C. ZIFA: Dimensionality reduction for zero-inflated single-cell gene expression analysis. Genome Biology. 2015;16(1).

(19) Bing-Kun Bao, Guangcan Liu, Changsheng Xu, Shuicheng Yan. Inductive robust principal component analysis. IEEE Transactions on Image Processing. 2012;21(8):3794-3800.

(20) Harrington P, Vieira N, Espinoza J, Nien J, Romero R, Yergey A. Analysis of variance–principal component analysis: A soft tool for proteomic discovery. Analytica Chimica Acta. 2005;544(1-2):118-127.

(21) Dicker L. Variance estimation in high-dimensional linear models. Biometrika. 2014;101(2):269-284.

(22) FAN L, WANG J. Clustering algorithms for mixed attributes based on rough set. Journal of Computer Applications. 2011;30(12):3377-3379.

(23) Dijkstra J, van Mill J. Erdos space and homeomorphism groups of manifolds. Memoirs of the American Mathematical Society. 2010;208(979):0-0.

(24) Wen G-H, Lu T-H, Jiang L-J, Wen J. Locally linear embedding based on relative manifold. Journal of Software. 2009;20(9):2376–86.

(25) Roe J. Index theory, coarse geometry, and topology of manifolds. Providence, RI: American Mathematical Society; 1996.

(26) Zhang J, Huang H, Wang J. Manifold learning for visualizing and analyzing high-dimensional Data. IEEE Intelligent Systems. 2010;.

(27) Tong Lin, Hongbin Zha. Riemannian manifold learning. IEEE Transactions on Pattern Analysis and Machine Intelligence. 2008;30(5):796-809.

(28) Balasubramanian M. The isomap algorithm and topological stability. Science. 2002;295(5552):7a-7.

(29) Attie O. Quasi-isometry classification of some manifolds of bounded geometry. Mathematische Zeitschrift. 1994;216(1):501-527.

(30) Chen L, Buja A. Local multidimensional scaling for nonlinear dimension reduction, graph drawing, and proximity analysis. Journal of the American Statistical Association. 2009;104(485):209–19.

(31) Chatfield C, Collins AJ. Multidimensional scaling. Introduction to Multivariate Analysis. 2018;:189–211.

(32) Crespo-Piazuelo D, Estellé J, Revilla M, Criado-Mesas L, Ramayo-Caldas Y, Óvilo C, et al. Characterization of bacterial microbiota compositions along the intestinal tract in pigs and their interactions and functions. Scientific Reports. 2018;8 (1).

(33) Huang Y-J, Li F-Z. Isospectral Manifold Learning Algorithm. Journal of Software. 2014;24(11):2656–66.

(34) Tang J-T, Wang T, Wang J. Shortest path approximate algorithm for complex network analysis. Journal of Software. 2011;22(10):2279–90.

(35) Chang Y, Hu C, Turk M. Probabilistic expression analysis on manifolds. Proceedings of the 2004 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 2004 CVPR. 2004.

(36) Silva CD, Herrmann FJ. Optimization on the hierarchical tucker manifold – applications to tensor completion. Linear Algebra and its Applications. 2015;481:131 –73.

(37) Akhbardeh A, Jacobs MA. Comparative analysis of nonlinear dimensionality reduction techniques for breast MRI segmentation. Medical Physics. 2012;39 (4):2275–89.

(38) Chu MT, Xu S-F. Spectral decomposition of real symmetric quadratic □-matrices and its applications. Mathematics of Computation. 2009;78(265):293–.

(39) Shen D, Zulch P, Disasio M, Blasch E, Chen G, Wang Z, et al. Manifold learning algorithms for sensor fusion of image and radio-frequency data. 2018 IEEE Aerospace Conference. 2018.

(40) Holmes E. (Supervised Learning) Genre section 1–detecting and characterizing known patterns. Practical Data Mining. 2011;:179–204.

(41) Zhang M, Alvarez RM, Levin I. Election forensics: Using machine learning and synthetic data for possible election anomaly detection. Plos One. 2019; 14(10).

ARTICLE INFORMATION

Senior Editor
Stefano A. Biasi

Reviewers and Section Editors
Caitlin Reintjes, Dalen Koncz, Kushi Malhotra

Formatting and Illustrations
Youssef El-Sayes

ACADEMIC REVIEW OPEN ACCESS

Reviewing Inequities in Primary Care Received by Indigenous Peoples in Ontario

Heba Shahaed[1], Guneet Sandhu[2], Eric Seidlitz[3]

1. McMaster University, Honours Health Sciences, Class of 2021
2. McMaster University, Honours Health Sciences, Class of 2021
3. McMaster University, Assistant Professor, Ph.D.

Received 11 October 2020
Accepted 9 November 2020
Published 4 December 2020

SUMMARY

High quality primary health care is important, as it often serves as the first point of contact for most Canadians with the health care system. The Indigenous peoples in Canada experience health inequities when compared to the non-Indigenous population. There is a great lack of literature on the quality of primary health care specifically regarding Indigenous communities in Ontario. This review collected information from available studies that investigated the state of primary health care in this population. To accomplish data collection, a specific search strategy and online databases were used to retrieve relevant articles. Numerous themes including inadequate cultural training of healthcare professionals, shortages of nurses and doctors, and inappropriate management of mental health, were identified. This data was used to make recommendations for how Ontario can improve the delivery of primary health care for this population. The recommendations that were made include strengthening the Indigenous healthcare workforce, providing comprehensive Indigenous cultural training, development of a preventative mental health policy and the integration of local Indigenous values, customs and beliefs into the primary care delivery model. Further research is needed in this field of study in order to outline all aspects of Indigenous primary health care in Ontario that requires improvement, and the necessary strategies to make this change.

ABSTRACT

Research has shown that Indigenous peoples in Canada experience health inequities when compared to the non-Indigenous population. High quality primary care has been described in literature; however, this has not been explored through the lens of Indigenous health. A scoping review was performed in order to investigate the quality of primary care received by indigenous peoples in Ontario. To conduct this review, a search of current literature on primary care in Indigenous communities in Ontario was performed. The studies examined in this review were derived from four different databases and many evaluated specific communities using a qualitative and quantitative approach. Several themes were identified including inadequate preparation and training of health care providers, physician and nursing shortages, strategies associated with improved quality of care, management of mental health, disparities in health service delivery station types and ineffective primary care impacts on hospitalizations. This literature search demonstrated a clear gap in the literature on the quality of primary care received by the Indigenous population in Ontario. Thus, further research is necessary in order to outline the current state of primary care being delivered to Indigenous populations in Ontario, and develop strategies to enhance the quality of care for this population.

Keywords: Indigenous, primary care, quality, Ontario, disparities

INTRODUCTION

The World Health Organization defines quality of care as "the extent to which health care services provided to individuals and patient populations improve desired health outcomes. In order to achieve this, health care must be safe, effective, timely, efficient, equitable and people-centred".[1] These principles can be applied in any care provision context, regardless of the location or features of the patient population. The Government of Canada states that primary health care is where most Canadians first interact with the healthcare system.[2] It encompasses the delivery of services as patients first contact the health care system and involves the coordination of these services by healthcare providers. Through effective care coordination, patients are able to receive continuity of care and can consult with different specialists in the healthcare system with ease.[2] It is important to understand that the quality of primary care received by patients in Canada is not uniform.[3]

Social Determinants of Health (SDOH) such as gender, race, socioeconomic status and ethnicity, including Indigenous status, can impact the quality of care received by patients and play a vital role in their health outcomes.[4-7]

In Canada, there are health inequities between the Indigenous population and the non-Indigenous population.[8] Healthcare is described as being inadequate, underfunded and characterized by systemic racism and discrimination for this population.[7,9-11] Indigenous peoples also experience disparities related to workforce participation, socioeconomic status, education and quality of living conditions.[12] The disparities in these SDOH further impact the health outcomes of Indigenous peoples.[12] There is an urgent need to eliminate the inequities in health between Indigenous and non-Indigenous peoples.[12] At the global level, there has been significant development in public policy to address these inequities; however, there is an absence in Canadian healthcare policy supporting the Indigenous population.[12] Currently, the Government of Canada has attempted to mitigate this absence by adopting practices in line with Indigenous culture, and build relationships with this population according to the Truth and Reconciliation Act.[13] This approach aims to address the determinants of health pertaining to the Indigenous population and is based on principles of social justice, human rights, equity and evidence-informed policy and practice.[13] Establishing relationships with cultural understanding and trust between healthcare providers and Indigenous peoples is one of the best ways to support the healing of the Indigenous population.[8]

Despite this governmental initiative, there is currently a substantial gap in the literature examining the healthcare experiences of this population in a primary care setting.[7] Given this gap in literature, coupled with the disparities in care that exist, the purpose of this scoping review is to investigate the quality of primary care that is received by the Indigenous population in Ontario.

METHODS

This scoping review uses the framework created by Arksey and O'Malley (2005) along with the modifications made to it by Levac et al. (2010) to guide the research process.[14,15] The Arksey and O'Malley paper outlined five distinct steps to perform a scoping review including: (1) identifying the research question, (2) identifying relevant studies, (3) study selection, (4) charting the data, and (5) collating, summarizing and reporting the results.[14] The methodology and data extraction tables were also informed by the structure employed by Pham et al. (2014).[16]

Research Inquiry

A scoping review is defined as the process of mapping existing literature in a research area that has not yet been reviewed in-depth.[17] It can be used to accomplish goals such as summarizing the findings of research, identifying a gap in the research of a specific topic, and providing evidence to inform practice and policy making.[14] The research question that this scoping review aimed to answer was: what is the quality of primary care received by the Indigenous peoples in Ontario?

Article Selection

The search was performed in February 2020 using four electronic databases: CINAHL/EBSCO (nursing and allied health; 1981–present), MEDLINE/PubMed (biomedical sciences, 1946–present), ISI Web of Knowledge (multidisciplinary current awareness; 1998–present) and Embase (biomedical and pharmacological;1974-present).

The search was done using a variety of databases that cover multiple disciplines. Limits were not placed on the search. The terms used in the search query were relevant to the quality of primary care and Indigenous individuals in Ontario. The search string was developed through consultation with a librarian at McMaster University. The patient population was identified using the University of Alberta OVID/MEDLINE search terms for Indigenous peoples in Ontario, along with the official and comprehensive list of First Nation communities in Ontario provided by the Government of Canada.[18,19] The following search terms were used: "Athapaskan or Saulteaux or Wakashan or Cree or Aboriginal* or Indigenous* or Metis or Ojibway or Chippewa or Mississauga* or Mohawk or MunseeDelaware or Anishinaabe or Nipissing or Seneca or "six nations"". [18,19] The search strategy employed can be found through this study's supplementary information.

Citations

Citations were imported into the screening and data extraction tool, Covidence, in order to streamline this process between data reviewers. This software enabled the removal of duplicate citations and allowed researchers to efficiently upload search results from databases, screen abstracts and full-text, as well as collect data, resolve disagreements and export data into a spreadsheet.

Article Selection

Studies were eligible for inclusion if they were in English, examined humans, pertained to Indigenous peoples in Ontario and involved primary care. Studies were excluded if they were published in any language but English, pertained to Indigenous peoples outside of Ontario or involved non-primary care.

A total of 540 hits were imported into Covidence. After the title and abstract screening process, 32 hits remained. After further examining the full-text articles for relevance, researchers were left with seven hits. The authors reviewed each citation and discussed any inconsistencies. An outline of this process can be found in **Figure 1.**

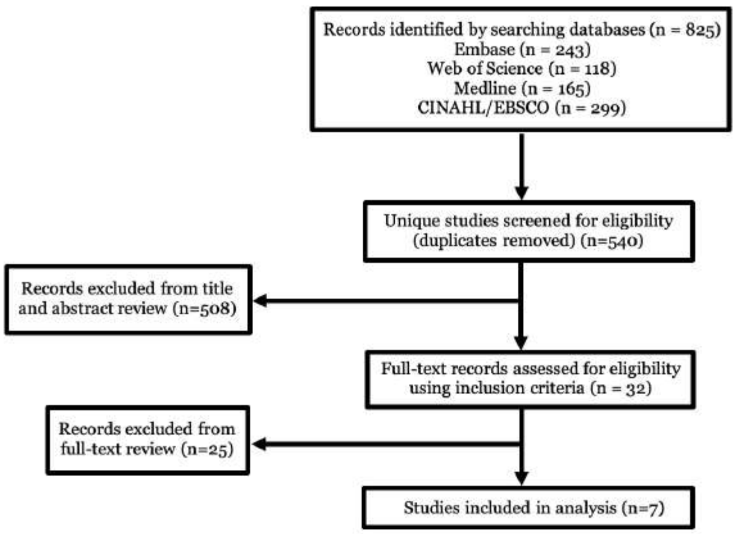

Figure 1. Flow diagram of study selection.

Data Organization

From a full-text review, selected articles were imported into a spreadsheet. Agreed upon and relevant categories, based on the Arksey and O'Malley (2005) scoping review protocol, were used to extract characteristics of each article. The characteristics of each study can be found through this study's supplementary information.

Data Analysis

Upon categorization of information in a spreadsheet, data was analyzed for common themes and ideas that arose among research articles. Similar ideas were grouped together to generate themes. The identification of themes was an organic process through which the authors presented novel ideas that would best define the patterns in the articles.

RESULTS

After the full-text screening process, a total of seven studies were identified that adequately fit the inclusion criteria. These studies ranged in type from scoping reviews to examining specific communities in Ontario using interviews and analysis of qualitative and quantitative data. Although all studies were conducted in Ontario, Canada, the specific locations within Ontario varied between studies. Three of the seven studies were conducted in specific communities such as Sioux Lookout, Kingfisher Lake, Wapakeka and Wunnimin Lake.[20-22] The remaining four studies were broadly conducted in communities across Ontario.[23-26] The date of publication of these studies also varies greatly. All studies were conducted after 2000, with the exception of a 1981 evaluation of a community.[20]

The literature was then analyzed to identify common themes which are outlined in **Table 1**. A total of six themes were identified; however, only four of these themes surfaced more than once. The most prominent themes, which were identified as physician and nursing shortage, strategies associated with improved quality of care, and inadequate preparation or training, each appeared in three of the seven studies. The remaining recurrent theme, management of mental health, appeared in two of the seven studies. The last two themes identified, the disparities in health service delivery station types, and ineffective primary care and impacts on hospitalizations, were each only present in one of the seven studies. A visual representation of this may be found in this study's supplementary information. **Table 1** identifies the specific themes found within each study.

Table 1. Quality of Care Related Themes Identified in Collected Literature.

Study	Theme
Ford-Gilboe, *Milbank Q*, 2018	Strategies associated with improved quality of care
Harfield, *Global Health*, 2018	Strategies associated with improved quality of care Inadequate preparation/training
Minore, *J Interprof Care*, 2004	Physician and nursing shortage Inadequate preparation/training Management of mental health
Minore, *Can J Nurs Res*, 2005	Physician and nursing shortage Inadequate preparation/training Management of mental health
Motta, *Point of Care*, 2015	Strategies associated with improved quality of care
Shah, *Am J Public Health*, 2003	Ineffective primary care and impacts on hospitalizations
Young, *Public Health Rep*, 1981	Physician and nursing shortage Disparities in health service delivery station types

Physician and Nursing Shortage

The studies conducted by Minore et al. in 2004 and 2005, in addition to the study by Young in 1981 all examined specific communities in Ontario that experienced a deficit in the number of healthcare professionals.[20-22] In the Minore et al. studies, the communities of Kingfisher Lake, Wapakeka and Wunnimin Lake were evaluated for the impacts of healthcare professional shortages and turnovers in regard to primary health outcomes.[21,22] Specifically, there was a distinct shortage in mental health nurses, resulting in serious detriments to patients' mental health status. [21,22] Further, the routine changes in nursing staff led to a constant introduction of nurses who were not educated regarding the cultural practices of Indigenous communities of northern Ontario and the realities of practicing in an isolated environment. [21,22] Namely, nurses experienced more isolation than they had anticipated, thus prompting them to leave the communities after a shorter period of time than usual. [22] These frequent staffing changes led to individuals being hesitant to utilize primary care services or continue the care they had started. [21,22] The short-term nature of the staffing translated to a lack of follow-up in the primary care received by the individuals of these communities. [21,22] As a result, patients abandoned treatment because they became obligated to retell their symptoms to unfamiliar nursing staff. [21,22]

Young's (1981) study found that the 25 Indigenous communities in Sioux Lookout in northwestern Ontario could be categorized as either having nursing stations or only having health stations.[20] Health stations are smaller than nursing stations and staffed by members of the community known as health aides, who have various training and experience. They help fill in the gaps by providing primary care services supplementary to visits by nurses and physicians.[20] Further, there is a significant physician shortage, as the nearest physician to these communities ranged from 40 to 750 kilometers away.[20] These shortages result in only half of those individuals that are sick actually using the available health services.[20]

Strategies Associated With Improved Quality of Care

The theme of strategies associated with improved quality of care was identified in the 2018 study by Ford-Gilboe et al., the 2018 study by Harfield et al. and a 2015 study conducted by Motta et al.[23-25] Ford-Gilboe et al. (2018) conducted interviews across Ontario to evaluate patient perceptions of the care they received in primary care settings.[23] These perceptions included their confidence in care providers and self-reported health outcomes.[23] The aim of this study was to determine if equity-oriented health care (EOHC) characterized by trauma and violence-informed, culturally safe, and contextually tailored care, would improve health outcomes including quality of life, chronic pain disability, Post-Traumatic Stress Disorder (PTSD) symptoms and depressive symptoms.[23] The authors found that providing EOHC, which seeks to reduce the consequences of structural inequalities (e.g. poverty, income, housing) on individual's access to services and the quality of care they receive, may improve patients' health outcomes over time.[23] EOHC may lead patients to have a greater level of confidence in their own ability to manage their health problems and have greater comfort and confidence in the primary care they receive.[23] Ultimately, this leads to improvements in depressive symptoms, PTSD symptoms and a higher quality of life.[23]

Harfield et al. (2018) investigated the characteristics that defined Indigenous primary care models.[24] The authors determined that a new primary health care service delivery model should integrate the numerous themes that were identified through the primary health care settings they investigated.[24] These themes include: accessible health services, community participation, continuous quality improvement, culturally appropriate and skilled workforce, flexible approaches to care, holistic health care, self-determination and empowerment.[24] The most significant factor that defines improved quality of care in Indigenous primary care service delivery models, is the role of culture.[24] Practices such as incorporating Indigenous artwork and signage, along with employing local Indigenous staff can help implement a culturally skilled workforce that takes into account values, customs and beliefs into practice.[24]

The study conducted by Motta et al. in 2015 examined the use of the Analytical and Clinical Excellence (ACE) program, an international Point of Care Testing (POCT) program for diabetes management for Indigenous peoples.[25] This program provided opportunities to improve the delivery of pathology services in rural and remote areas. Speed testing allowed clients to receive faster results, reduce their number of visits, reduce wait times and ultimately led to better management of diabetes.[25] In an Indigenous context, this program enabled culturally sensitive training for healthcare professionals and allowed for knowledge transfer to participating communities, providing them with the resources they need to maintain the program long-term.[25] This study highlighted how POCT programs can play a role in better outcomes for Indigenous individuals.[25]

Inadequate Preparation or Training

This theme was identified in two papers written by Minore et al. in 2004 and 2005. [21,22] Both papers examined concerns regarding continuity of healthcare in three remote northern Indigenous communities. [21,22] These papers found that inadequate preparation among healthcare professionals including nurses recruited to northern Indigenous communities greatly affected the continuity of care.[21,22] The 2005 paper had a specific focus on nurses and identified a long time practitioner who mentioned that agency nurses who arrived did not have appropriate preparation, as they "had never been in the north, had never been trained to be in the north, had never been oriented on how to work in the north."[22] The lack of cultural awareness, due to systemic training errors and personal ignorance, plays a major role in acting as a barrier between nurses in these communities and their patients. It is reported that these nurses are often in cultural shock.[22] This lack of cultural awareness can result in nurses making social errors such as not avoiding eye contact with elderly patients, which can affect patient-provider relationships.[22] Additionally, a lack of knowledge to patient lifestyle factors can also cause poor treatment suggestions or misunderstandings.[22] One of the nurses interviewed in the study expressed that once, one of her colleagues was frustrated and proceeded to question her elderly diabetic patient, regarding why they had not bathed their infected foot as suggested. Unfortunately, this nurse did not realize that obtaining and heating water was an exhaustive process that would have been very difficult for the patient.[22]

Furthermore, the study conducted by Harfield et al. (2018) emphasized the importance of a culturally appropriate and skilled workforce.[24] The lack of these attributes can often contribute to poor health outcomes found in Indigenous populations when compared to non-Indigenous populations. Culturally appropriate service delivery is characterized by creating a welcoming and comforting space.[24] Further, having a workforce that is characterized by cultural respect, social justice and equality is vital to building trust with communities.[24] One of the best ways to ensure community beliefs and values are being prioritized in primary care delivery is through employing local Indigenous staff. This would also have several other benefits as these employees can serve as interpreters to translate local languages to non-Indigenous staff, and they can also mentor non-Indigenous staff members to ensure cultural competency.[24]

Management of Mental Health

This theme was identified in two papers written by Minore et al. in 2004 and 2005, that examined concerns regarding continuity of healthcare. [21,22] These papers outlined how it is possible to achieve appropriate care for oncology patients and those with diabetes, but disparities exist when looking at the management of mental health care for Indigenous populations. [21,22] In these three communities, once clients were stable, they were discharged back home where follow-up was inadequate to ensure the good health of these individuals. [21,22] These communities are prepared with crisis intervention strategies but do not have the framework in place for mental health maintenance and prevention services. Both papers also identified that Health Canada lacks a concrete Indigenous mental health policy. [21,22]

Disparities in Health Service Delivery Station Types

The 1981 paper written by Young identified this theme in the analysis of 25 Indigenous communities.[20] A disparity exists among the communities between access to either nursing stations, or health stations resulting in only half of the individuals who are sick being able to utilize these resources.[20] Furthermore, there is an imbalance between the gender and age range of the patients that use these primary care services.[20] For example, when evaluating the use of health services amongst those reported to be sick, highest users are under the age of five, over the age of 45, and female. Young adults had the lowest rates of health service use.[20] There is no uniform level of care provided at each station type, which impacts the health outcomes of individuals that visit one station type as opposed to another.[20] Health stations have less medical resources and types of professionals compared to nursing stations, resulting in a different type and extent of primary care.[20]

Ineffective Primary Care and Impacts on Hospitalizations

This theme was identified in a study by Shah et al. (2003).[26] This study examined the accessibility and quality of primary care for the Indigenous population in Ontario.[26] Researchers compared a group of Indigenous individuals with a non-Indigenous population, where both groups experienced the same level of geographic isolation and low socioeconomic status.[26] Upon examination of ambulatory care-sensitive (ACS) conditions and utilization of referral care-sensitive (RCS) procedures, it was found that

Indigenous individuals had higher ACS hospitalization rates and reduced RCS procedure utilization, indicating poor quality of primary care.[26] As timely and effective primary care for ACS conditions could potentially prevent and reduce hospitalizations, the increased hospitalization rate for ACS conditions amongst this population signifies disparities in care. The rate of utilization of RCS procedures can also indicate the quality of primary care, as high rates signify that a provider has been able to identify a care need in their client and an appropriate referral has been facilitated. The low RCS procedure utilization rates reported by Shah et al. (2003), however, signify a disparity in primary care delivery for this population.[26]

DISCUSSION

Through examining the seven studies included in this scoping review, the primary issue that was identified was a significant lack of literature with a comprehensive focus pertaining to the quality of primary care in the Indigenous population. Additionally, the time frame of these studies presents a major concern. The majority of literature can be considered outdated, as four of the seven studies were published more than 15 years ago. The studies therefore do not take into account the specific needs and concerns of the current Indigenous population.

Although a comprehensive search was performed through numerous databases, the stark reality is that only seven articles met the inclusion criteria of being conducted in Ontario, pertaining to Indigenous peoples, and being written in English. When taking into account that Ontario has the largest Indigenous population when compared to any other province or territory in Canada, and that this population has grown in the recent decade, this lack of literature becomes even more consequential.[27] Further, there exists a lack of systematic and scoping reviews that comprehensively investigate the quality of primary care in Indigenous communities all across Ontario. If improvements are to be made to the quality of Indigenous primary care and policy regulating this care, the current level of literature is inadequate to inform these decisions. These gaps in the literature must be overcome with thorough research and evaluation of the current quality of primary care for the Indigenous people in Ontario.

Of the themes that arose in this analysis, the most prominent themes included: inadequate preparation and training, physician and nursing shortage, strategies associated with improved quality of care and management of mental health.

Our findings revealed that a lack of culturally sensitive preparation and training of healthcare providers, creates a major barrier in the delivery of high quality primary care. This creates a disconnect in the patient-provider relationship and negatively impacts health outcomes. With healthcare providers being in cultural shock, they often make errors in communication which can pose significant challenges.[21,22]

The shortage of healthcare providers in areas with a high Indigenous population further contributes to gaps in care. This is an area of major concern, as it can lead to poor health outcomes and abandonment of treatment by patients.[21,22] For example, when patients become obligated to retell their health concerns to constantly rotating staff, they become discouraged and are hesitant to return to treatment.[21,22] Thus, even when patients' symptoms are addressed in the short-term, and follow up is needed by medical staff, it often does not occur.

In addition to identifying the significant challenges faced by the Indigenous population in Ontario, when it comes to primary health care, the studies identified in this scoping review also touch upon limited strategies that can be used to help overcome these disparities. For example, the literature has suggested that an EOHC model can predict positive health outcomes such as a decrease in depressive symptoms and can contribute to a greater level of confidence and comfort in care providers.[23] However, this model of care is not currently in place in Ontario. EOHC is crucial in the Indigenous population because it aims to reduce structural inequalities such as disparities in income and housing, which are prevalent in Indigenous communities.[23] Further, strategies such as implementing speed testing programs like ACE, which also consider the values, customs and beliefs of communities, can further help to improve health outcomes.[25]

It is also alarming that only two of the seven studies discussed mental health care, considering the scope of this issue in the Indigenous population in Ontario.[28] The studies reviewed in this article demonstrated how the management of mental health for Indigenous patients is poor compared to other diseases.[21,22] For example, Minore et al. (2004) note that the instance of suicide is so high that mental health care is centred around crisis response, as opposed to prevention and routine treatment.[21] Further, once patients become stabilized following a mental-health crisis, follow-up is inadequate, thus presenting the risk that the patient re-experiences the same mental health problem. This is of immediate concern given the magnitude of the mental health challenges faced by the Indigenous population.[28] For example, statistics show that suicide amongst youth in the Indigenous population occurs five to six times more than non-Indigenous youth in Canada.[29]

Strengths and Limitations

A strength of this study was the use of the screening tool, Covidence, as it streamlined the process by which the authors screened and extracted data from the studies. There were no studies that were unaccounted for between the process of deeming studies eligible from title and abstract review, to screening the full-text, and then subsequently extracting data. Furthermore, the systematic approach that was utilized to extract data helped to ensure that the same information was extracted from each study and to ensure consistency between study authors. Each citation was reviewed by two independent reviewers who regularly met to resolve conflicts and discuss any inconsistencies.

Consultation with a librarian ensured that the search strategy was comprehensive and valid for the aim of this scoping review. However, it is possible that this review may not have identified all the existing literature on the quality of primary care for the Indigenous population in Ontario. Since grey literature was not included in the search, publications that fit under this category that pertained to quality of primary care in Indigenous communities in Ontario were not included. Another possible limitation of this study is the biased nature of the databases utilized in this scoping review. For example, although ISI Web of Knowledge is a multidisciplinary database, databases such as PubMed, CINAHL/EBSCO, and Embase are primarily biased towards health and sciences. Databases focused on humanities and social sciences would have helped provide a greater scope of literature.

Recommendations to Improve Quality of Primary Care

In regards to the shortage of healthcare professionals across Indigenous communities, the issue of frequent staff turnover can be addressed by implementing a program where the same group of healthcare providers rotate in and out of a community.[21,22] Through reduction of healthcare staff turnover, health outcomes, continuity of care and cost-effectiveness of care will be improved.[30] In order to do so, the prioritization of rural or remote based applicants and Indigenous health care workers must be employed.[30] Further, adequate infrastructure and funding of medical services is needed for work that is professionally satisfying, thus reducing the chances of staff turnover.[30] In order to promote staff retention, adequate personal and family support, professional development opportunities and alternative models of scheduling are necessary.[31] For example, creating a rotating cycle of working alternative months helps to maintain the same group of healthcare workers while providing staff with opportunities to return to their preferred environment.[31] This limits the number of unfamiliar faces that are introduced to a health care setting and helps to reduce the hesitation that individuals experience from re-explaining their health concerns to new healthcare staff each time they visit a primary care setting. [21,22]

System wide accommodations to collaborate with paraprofessional staff in the community can also help enhance patient care. As these staff members are well-versed in community values and beliefs, they can play a significant role in implementing long-term programs and improving patient outcomes.[21,22]

Furthermore, adequate training should be provided to all healthcare professionals who practice in Indigenous communities. This training should incorporate local customs, values, and beliefs into the model of care. [21,22] Training should be provided regardless of the length of the healthcare professionals' employment in an Indigenous community. Specifically, the role of elders and Indigenous governance in the care model should be respected to better engage with patients. EOHC would be a valuable tool to integrate into the current primary care system in order to reduce the effects of structural inequalities that may result in poor health outcomes.[23] Making EOHC a priority of healthcare providers would help to mitigate some of the effects of unequal housing, income and poverty that impacts the health of Indigenous populations in Ontario.[23]

Resources including the Indigenous Health Program of Alberta Health Services can be further explored to better understand how to create culturally competent, and sustainable partnerships between Indigenous peoples and stakeholders in the healthcare system.[32] Additionally, training such as the Cultural Safety Online Course provided by Island Health in British Columbia, can further improve cultural competency. This course encourages culturally safe and respectful care.[33]

Mental health is also an area where disparities in care exist for the Indigenous population. [21,22] As a result, a comprehensive mental health policy should be developed by Health Canada for this population to ensure adequate care. Speed testing through programs such as POCT have also shown great benefits and should be employed when working with Indigenous patients to ensure efficiency of care.[25]

The overarching recommendation made by this scoping review is to conduct more in-depth research on the quality of primary care received by the Indigenous population in Ontario. To mitigate the substantial lack of literature on this subject, consistent and thorough data collection is crucial. In doing so, primary care can be tailored to meet the unique needs of each Indigenous community.

CONCLUSION

This scoping review involved performing a literature search to investigate the quality of primary care received by Indigenous individuals in Ontario. There was a need to identify the gaps in literature investigating the quality of primary care for Indigenous patients due to the current lack of conclusive and comprehensive evidence. There is a clear need for a significant transformation in the Indigenous primary care model in order to better meet the specific needs of these communities. This is crucial, as the Indigenous population in Ontario is the largest of any province or territory in Canada.[27] The implications of an inadequate health care model are significant. Action is urgently needed to ensure more research in this field along with the development of policies to improve the quality of primary care received by this population.

ACKNOWLEDGEMENTS

The authors would like to thank librarian Denise Smith from the McMaster Health Sciences Library for her support and expertise in creating a comprehensive search strategy. This work did not receive funding. The authors report no conflicts of interest.

ARTICLE INFORMATION

Senior Editor
Reza Khorvash

Reviewers and Section Editors
Kasia Tywonek, Naomi Suzuki

Formatting and Illustrations
Danial Aminaei

REFERENCES

(1) WHO | What is quality of care and why is it important? [Internet]. WHO. World Health Organization; [cited 2020 Mar 9]. Available from: http://www.who.int/maternal_child_adolescent/topics/quality-of-care/definition/en/
(2) Canada H. Canada's health care system [Internet]. Government of Canada. 2016 [cited 2020 Mar 9]. Available from: https://www.canada.ca/en/health-canada/services/canada-health-care-system.html
(3) Dhalla IA, Tepper J. Improving the quality of health care in Canada. CMAJ. 2018 Oct 1;190(39):E1162–7.
(4) Andermann A. Taking action on the social determinants of health in clinical practice: a framework for health professionals. CMAJ. 2016 Dec 6;188(17–18):E474–83.
(5) Arpey NC, Gaglioti AH, Rosenbaum ME. How socioeconomic status affects patient perceptions of health care: a qualitative study. J Prim Care Community Health. 2017 Jul 1;8(3):169–75.
(6) Egede LE. Race, ethnicity, culture, and disparities in health care. J Gen Intern Med. 2006 Jun;21(6):667–9.
(7) Goodman A, Fleming K, Markwick N, Morrison T, Lagimodiere L, Kerr T. "They treated me like crap and I know it was because I was Native": the healthcare experiences of Aboriginal peoples living in Vancouver's inner city. Soc Sci Med. 2017 Apr;178:87–94.
(8) Guerra O, Kurtz D. Building collaboration: A scoping review of cultural competency and safety education and training for healthcare students and professionals in Canada. Teach Learn Med. 2017 Apr 3;29(2):129–42.
(9) The Canadian Encyclopedia. Health of Indigenous peoples in Canada [Internet]. [cited 2020 Nov 14]. Available from: https://www.thecanadianencyclopedia.ca/en/article/aboriginal-people-health
(10) Kallil S. Canada's national failure: Indigenous health. Juxtaposition [Internet]. 2019 Nov 24 [cited 2020 Nov 14]; Available from: https://juxtamagazine.org/2019/11/24/canadas-national-failure-indigenous-health/
(11) Matthews R. The cultural erosion of Indigenous people in health care. CMAJ. 2017 Jan 16;189(2):E78–9.
(12) Richmond CAM, Cook C. Creating conditions for Canadian aboriginal health equity: the promise of healthy public policy. Public Health Rev. 2016 Jul 20;37(1):2.
(13) Policy on Indigenous Relations and Reconciliation | Canadian Public Health Association [Internet]. [cited 2020 Mar 9]. Available from: https://www.cpha.ca/policy-indigenous-relations-and-reconciliation
(14) Arksey H & O'Malley L. Scoping studies: towards a methodological framework. Int. J. Soc. Res. 2005;8(1): 19-32.
(15) Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. Implement Sci. 2010 Sep 20;5(1):69.
(16) Pham MT, Rajić A, Greig JD, Sargeant JM, Papadopoulos A, McEwen SA. A scoping review of scoping reviews: advancing the approach and enhancing the consistency. Res Synth Methods. 2014 Dec;5(4):371–85.
(17) Armstrong R, Hall BJ, Doyle J, Waters E. 'Scoping the scope' of a cochrane review. J Public Health (Oxf). 2011 Mar 1;33(1):147–50.
(18) Library PSTJWS. Subject guides: health sciences search filters: Indigenous peoples [Internet]. [cited 2020 Mar 9]. Available from: https://guides.library.ualberta.ca/health-sciences-search-filters/indigenous-peoples
(19) Ministry of Indigenous Affairs. Ontario First Nations maps [Internet]. [cited 2020 Mar 9]. Available from: https://www.ontario.ca/page/ontario-first-nations-maps
(20) Young TK. Primary health care for isolated Indians in northwestern Ontario. Public Health Rep. 1981;96(5):391-397.
(21) Minore B, Boone M, Katt M, Kinch P, Birch S. Addressing the realities of health care in northern aboriginal communities through participatory action research. J Interprof Care. 2004 Jan;18(4):360–8.
(22) Minore B, Boone M, Katt M, Kinch P, Birch S, Mushquash C. The effects of nursing turnover on continuity of care in isolated first nation communities. CJNR. 2005, 37(1):86-100.
(23) Ford–Gilboe M, Wathen CN, Varcoe C, Herbert C, Jackson BE, Lavoie JG, et al. How equity-oriented health care affects health: key mechanisms and implications for primary health care practice and policy. The Milbank Q. 2018;96(4):635–71.
(24) Harfield A, Davy C, McArthur A, Munn Z, Brown A, Brown N. Characteristics of Indigenous primary health care service delivery models: a systematic scoping review. Glob. Health. 2018;14(2).
(25) Motta L, Shepard M. The international analytical and clinical excellence program point-of-care testing for diabetes management. Point Care. 2015 Sep;14(3):76–80.
(26) Shah BR, Gunraj N, Hux JE. Markers of access to and quality of primary care for Aboriginal people in Ontario, Canada. Am J Public Health. 2003 May;93(5):798–802.
(27) Ministry of Indigenous Affairs. In the spirit of reconciliation: Ministry of Indigenous Relations and Reconciliation's first 10 years: Indigenous peoples in Ontario [Internet]. [cited 2020 Mar 9]. Available from: https://www.ontario.ca/document/spirit-reconciliation-ministry-indigenous-relations-and-reconciliation-first-10-years/indigenous-peoples-ontario
(28) Khan S. Aboriginal mental health: the statistical reality [Internet]. [cited 2020 Mar 9]. Available from: https://www.heretohelp.bc.ca/aboriginal-mental-health-statistical-reality
(29) CAMH. Mental illness and addiction: facts and statistics [Internet]. [cited Nov 1 2020]. Available from: https://www.camh.ca/en/driving-change/the-crisis-is-real/mental-health-statistics
(30) Wakerman J, Humphreys JS, Russell D, Guthridge S, Bourke L, Dunbar T, et al. Remote health workforce turnover and retention: what are the policy and practice priorities? Human Resources for Health. 2019;17(99).
(31) Zhao Y, Russell DJ, Guthridge S, Ramjan M, Jones MP, Humphreys JS, et al. Costs and effects of higher turnover of nurses and Aboriginal health practitioners and higher use of short-term nurses in remote Australian primary care services: an observational cohort study. BMJ Open. 2019;9:e023906.
(32) Alberta Health Services. Indigenous health program [Internet]. [cited 2020 Nov 1]. Available from: https://www.albertahealthservices.ca/findhealth/service.aspx
(33) Island Health. Aboriginal health cultural safety [Internet]. [cited 2020 Nov 1]. Available from: https://www.islandhealth.ca/learn-about-health/aboriginal-health/aboriginal-health-cultural-safety

COVID-19 vs. History's Pandemics

The spread of a new virus has caused a worldwide effort to combat the COVID-19 pandemic. Humans, however, have experienced many viral outbreaks in the past. Historical data can help inform current analyses and decisions. Thus, this infographic compares COVID-19 with past pandemics and outbreaks to showcase similarities and differences. This can allow for a better understanding of COVID-19 in the context of past events and the changing perspectives over the past century.

TOTAL DEATHS COMPARED

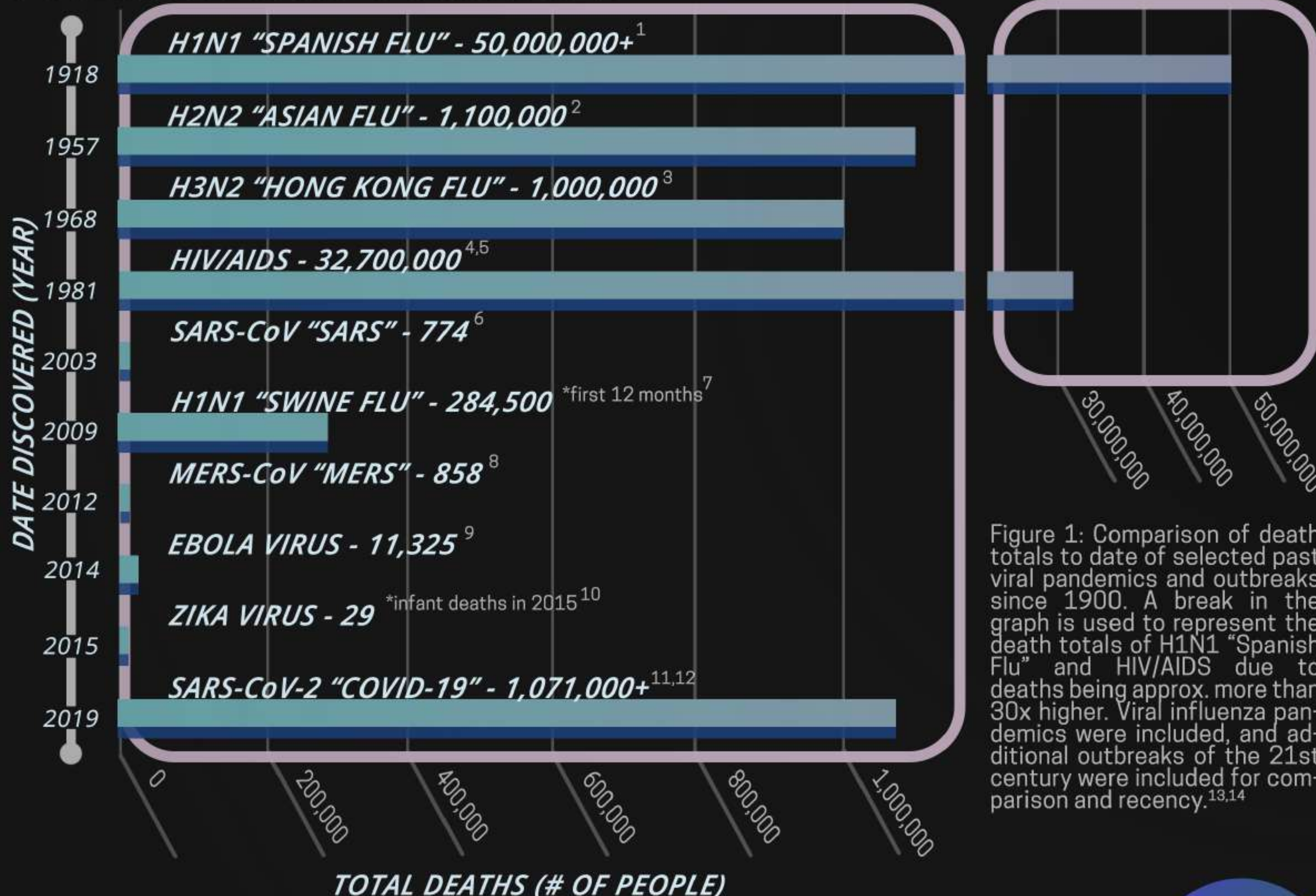

Figure 1: Comparison of death totals to date of selected past viral pandemics and outbreaks since 1900. A break in the graph is used to represent the death totals of H1N1 "Spanish Flu" and HIV/AIDS due to deaths being approx. more than 30x higher. Viral influenza pandemics were included, and additional outbreaks of the 21st century were included for comparison and recency.[13,14]

ESTIMATION OF CONTAGIOUSNESS

The Basic Reproductive Ratio (R_0) is a value used to represent the number of secondary cases that would be caused by one infected person in a susceptible population.[15] R_0 can vary and depends on many variables such as human activity, seasonal factors, the pathogen, and modeling assumptions. When used correctly, it is a crucial epidemiological estimation of the contagiousness of a disease.[15]

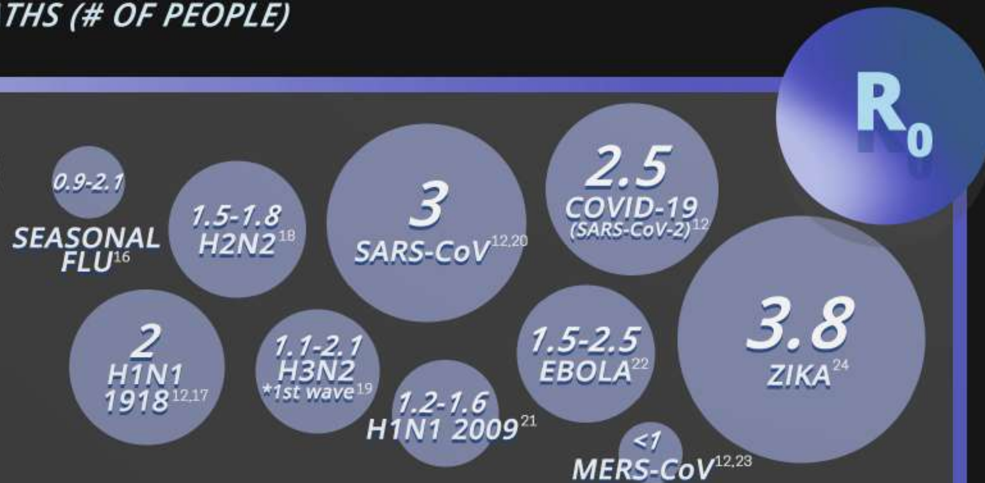

Figure 2: The Basic Reproductive Ratio (R_0) of viral outbreaks were represented using circle sizes proportional to their values. Values were pulled from literature and rounded, but may vary by study.

Angelina Lam[1]
1. McMaster University, Honours Integrated Science, Class of 2023

Received 15 October 2020
Accepted 12 November 2020
Published 4 December 2020

ARTICLE INFORMATION

Senior Editor
Reza Khorvash

Reviewers and Section Editors
Emerald Lin, Keerat Grewal, Danial Aminaei

RESPONSES & PERCEPTIONS

Advancements in technology, globalization, and changing news perceptions have influenced pandemic management over the years.[25] Since 1918, these changing factors have shifted the way outbreaks are responded to and perceived.

H1N1 "SPANISH FLU"

The Spanish Flu infected one-third of the world's population, with its spread heightened by the war.[1,26] Despite the isolation and hygiene measures that were put in place, the lack of vaccines and antibiotics led to an inevitably disastrous outcome.[1] Nonetheless, it sparked increasing research on influenza.[26]

THE MID-1900s AND ADVANCEMENTS

Viruses were discovered and isolated from people in the 1930s.[27] By the second half of the 20th century, the World Health Organization played a major role in the surveillance of disease, presenting itself as a reliable source of pandemic information.[26] By this time, vaccinations for influenza were widely accepted.[26]

21ST CENTURY OUTBREAKS AND CONSIDERATIONS

By the 21st century, politics became heavily involved in preparedness as pandemics were sometimes treated as a "security threat".[26(p.96)] Additionally, SARS, H1N1, Ebola, and ZIKA brought a focus on mental health, balancing preparedness and panic, quickly containing outbreaks, and critically evaluating information on social media.[10,28]

1918 TO 2019

SIMILARITIES:

use of masks[29,30]

importance of quick response and containment[29]

isolation methods to try and lessen spread[29]

DIFFERENCES:

social distancing seems to be more effective in 2019 than in 1918[29,31]

quick identification of SARS-CoV-2 compared to confusion in identifying H1N1[27,32,33]

REFERENCES

1.Centers for Disease Control and Prevention. 1918 pandemic (H1N1 virus) [Internet]. 2019 [cited 2020 Oct 11]. Available from: https://www.cdc.gov/flu/pandemic-resources/1918-pandemic-h1n1.html
2.Centers for Disease Control and Prevention. 1957-1958 pandemic (H2N2 virus) [Internet]. 2019 [cited 2020 Oct 11]. Available from: https://www.cdc.gov/flu/pandemic-resources/1957-1958-pandemic.html
3.Centers for Disease Control and Prevention. 1968 pandemic (H3N2 virus) [Internet]. 2019 [cited 2020 Oct 11]. Available from: https://www.cdc.gov/flu/pandemic-resources/1968-pandemic.html
4.Centers for Disease Control and Prevention. The HIV/AIDS epidemic: the first 10 years [Internet]. Morbidity and Mortality Weekly Report (MMWR). 1991 [cited 2020 Oct 14]. Available from: https://www.cdc.gov/mmwr/preview/mmwrhtml/00001997.htm
5.Joint United Nations Programme on HIV/AIDS (UNAIDS). Global HIV & AIDS statistics — 2020 fact sheet [Internet]. 2020 [cited 2020 Oct 11]. Available from: https://www.unaids.org/en/resources/fact-sheet
6.Centers for Disease Control and Prevention. SARS basics fact sheet [Internet]. 2017 [cited 2020 Oct 11]. Available from: https://www.cdc.gov/sars/about/fs-sars.html
7.Dawood FS, Iuliano AD, Reed C, Meltzer MI, Shay DK, Cheng P-Y, et al. Estimated global mortality associated with the first 12 months of 2009 pandemic influenza A H1N1 virus circulation: a modelling study. Lancet Infect Dis. 2012 Sep 1;12(9):687–95.
8.Memish ZA, Perlman S, Kerkhove MDV, Zumla A. Middle East respiratory syndrome. The Lancet. 2020 Mar 28;395(10229):1063–77.
9.Centers for Disease Control and Prevention. 2014-2016 Ebola outbreak in West Africa [Internet]. 2019 [cited 2020 Oct 11]. Available from: https://www.cdc.gov/vhf/ebola/history/2014-2016-outbreak/index.html
10. Huremović D. Brief history of pandemics (pandemics throughout history). Psychiatry Pandemics. 2019 May 16;7–35.
11. John Hopkins University Coronavirus Resource Center. COVID-19 map [Internet]. Johns Hopkins Coronavirus Resource Center. 2020 [cited 2020 Oct 10]. Available from: https://coronavirus.jhu.edu/map.html
12. Petersen E, Koopmans M, Go U, Hamer DH, Petrosillo N, Castelli F, et al. Comparing SARS-CoV-2 with SARS-CoV and influenza pandemics. Lancet Infect Dis. 2020 Sep;20(9):e238–44.
13. Samal J. A historical exploration of pandemics of some selected diseases in the world. 2014 Mar 1;1654.
14. LePan N. Visualizing the history of pandemics [Internet]. Visual Capitalist. 2020 [cited 2020 Oct 12]. Available from: https://www.visualcapitalist.com/history-of-pandemics-deadliest/
15. Delamater PL, Street EJ, Leslie TF, Yang YT, Jacobsen KH. Complexity of the basic reproduction number (R0). Emerg Infect Dis. 2019 Jan;25(1):1–4.
16. Chowell G, Miller MA, Viboud C. Seasonal influenza in the United States, France, and Australia: transmission and prospects for control. Epidemiol Infect. 2008 Jun;136(6):852–64.
17. Coburn BJ, Wagner BG, Blower S. Modeling influenza epidemics and pandemics: insights into the future of swine flu (H1N1). BMC Med. 2009 Jun 22;7(1):30.
18. Cobos AJ, Nelson CG, Jehn M, Viboud C, Chowell G. Mortality and transmissibility patterns of the 1957 influenza pandemic in Maricopa County, Arizona. BMC Infect Dis. 2016 Aug 11;16(1):405.
19. Jackson C, Vynnycky E, Mangtani P. Estimates of the transmissibility of the 1968 (Hong Kong) influenza pandemic: evidence of increased transmissibility between successive waves. Am J Epidemiol. 2010 Feb 15;171(4):465–78.
20. Bauch CT, Lloyd-Smith JO, Coffee MP, Galvani AP. Dynamically modeling SARS and other newly emerging respiratory illnesses: past, present, and future. Epidemiol Camb Mass. 2005 Nov;16(6):791–801.
21. Fraser C, Donnelly CA, Cauchemez S, Hanage WP, Kerkhove MDV, Hollingsworth TD, et al. Pandemic potential of a strain of influenza A (H1N1): early findings. Science. 2009 Jun 19;324(5934):1557–61.
22. Althaus CL. Estimating the reproduction number of Ebola Virus (EBOV) during the 2014 outbreak in West Africa. PLOS Curr Outbreaks [Internet]. 2014 Sep 2 [cited 2020 Oct 11]; Available from: index.html%3Fp=40381.html
23.World Health Organization. WHO MERS global summary and assessment of risk [Internet]. World Health Organization; 2018 Aug p. 2. Available from: https://www.who.int/csr/disease/coronavirus_infections/risk-assessment-august-2018.pdf
24. Towers S, Brauer F, Castillo-Chavez C, Falconar AKI, Mubayi A, Romero-Vivas CME. Estimate of the reproduction number of the 2015 Zika virus outbreak in Barranquilla, Colombia, and estimation of the relative role of sexual transmission. Epidemics. 2016 Dec 1;17:50–5.
25. Parmet WE, Rothstein MA. The 1918 influenza pandemic: lessons learned and not—introduction to the special section. Am J Public Health. 2018 Nov;108(11):1435–6.
26. Kamradt-Scott A. Changing perceptions: of pandemic influenza and public health responses. Am J Public Health. 2012 Jan;102(1):90–8.
27. Centers for Disease Control and Prevention. Influenza historic timeline [Internet]. 2019 [cited 2020 Oct 11]. Available from: https://www.cdc.gov/flu/pandemic-resources/pandemic-timeline-1930-and-beyond.htm
28. LeDuc JW, Barry MA. SARS, the first pandemic of the 21st Century. Emerg Infect Dis. 2004 Nov;10(11):e26.
29. World Health Organization Writing Group. Nonpharmaceutical interventions for pandemic influenza, national and community measures. Emerg Infect Dis. 2006 Jan;12(1):88–94.
30. Centers for Disease Control and Prevention. Use of masks to help slow the spread of COVID-19 [Internet]. Centers for Disease Control and Prevention. 2020 [cited 2020 Oct 11]. Available from: https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/diy-cloth-face-coverings.html
31. Thu TPB, Ngoc PNH, Hai NM, Tuan LA. Effect of the social distancing measures on the spread of COVID-19 in 10 highly infected countries. Sci Total Environ. 2020 Nov 10;742:140430.
32. Eyler JM. The state of science, microbiology, and vaccines circa 1918. Public Health Rep. 2010;125(Suppl 3):27–36.
33. Wang C, Horby PW, Hayden FG, Gao GF. A novel coronavirus outbreak of global health concern. The Lancet. 2020 Feb 15;395(10223):470–3.

OPEN ACCESS

The Role of Public Health Communication in Combating Vaccine Hesitancy: A Historical Comparison

Isabel Dewey[1]

1. McMaster University, Honours Life Science, Class of 2021

Received 22 October 2020
Accepted 10 November 2020
Published 4 December 2020

SUMMARY

Within this piece, a crucial aspect of public health is explored: science communication. When examining what drives vaccine hesitancy, a global public health issue, it becomes evident that science communication through the media, to a degree, is at fault. This piece looks back on the first instance of vaccine hesitancy surrounding the smallpox vaccination in the early nineteenth century. When taking a closer look at the historic smallpox pandemic, government responses to concerned individuals were beneficial in easing public concerns. However, similar government action has not been taken in response to newer vaccination resistance, as seen with the MMR vaccine. This piece describes the extensive media coverage and spread of misinformation regarding Andrew Wakefield's retracted research that linked vaccines to autism. To conclude, this piece realizes the differences between the smallpox and MMR vaccines. It attributes current hesitancy and the rise of anti-vaccination movements to poor science communication and government responses. Vaccine hesitancy is a significant public health issue that needs to be addressed, especially with the rise of new vaccines for the current COVID-19 pandemic.

ABSTRACT

In the current COVID-19 global health crisis, discussions of vaccine safety and hesitancy are being brought to light, as they were during many historical pandemics. In order to suggest effective public health interventions, it is important to examine the historically conventional interventions implemented during previous pandemics. In this review, the governmental role and communication strategies during the smallpox and the measles, mumps, and rubella (MMR) vaccine hesitancies are compared. Specifically, it assesses how these factors may have contributed to vaccine hesitancy and the difference in outcomes. This discussion emphasizes the importance of effective science communication and public health interventions in the prevention and eradication of diseases.

Keywords: MMR, smallpox, vaccine, science communication

INTRODUCTION

In the current media landscape, both credible and non-credible scientific information can be widely disseminated. As a result, misinformed opinions can be posted on the internet for anyone to access. People often have no way to validate these claims, increasing their vulnerability to being influenced. Before the internet, distribution of public health information was much more controlled. Misinformation has fueled many controversial public health debates, most prominently, vaccine hesitancy. This can be seen in the controversies of the measles, mumps, and rubella (MMR) vaccine, as well as the smallpox vaccination in the nineteenth century. When examining these two cases, it is crucial to ask what these debates have in common. Are differences in debates, governmental responses and media communication responsible for their outcomes?

SMALLPOX ANTI-VACCINATION MOVEMENT OF THE 19TH CENTURY

In the early nineteenth century, an anti-vaccination movement arose in response to a novel vaccination for smallpox.[1] Smallpox was a devastating illness, whose eradication in 1980 is one of the World Health Organization's greatest public health achievements.[1] In the late eighteenth century, the first scientific attempt to control the disease with vaccinations was led by Edward Jenner. He theorized that the immunity of individuals who had survived the disease could be replicated and used as a preventative vaccination.[1] This novel idea came with extensive skepticism. Many individuals were worried about the unknown effectiveness of these vaccinations. In addition, many concerns were based on religious beliefs.[2] In the nineteenth century, disease was largely thought to be due to sin, with vaccination seen as an attempt to interfere with God's will.[2]

As a response to this rising fear and distrust, Vaccination Acts were created to enforce vaccinations and protect public health. The first Vaccination Act in 1840 provided free vaccinations to the poor. It also outlawed the formerly used procedure called variolation, which was much more dangerous than vaccination.[3] In certain geographical areas, the acts proved to be effective, but in most regions, they were met with resistance.[3] Following the Vaccination Act of 1853, the revised act of 1867 mandated vaccinations for anyone under the age of 14.[4] This law was fought by the Anti-Compulsory Vaccination League, which had a seven-point statement focusing on the infringement of personal autonomy.[4]

Some anti-vaccination journals include the *Anti-Vaccinator,* the *National Anti-Compulsory Vaccination Reporter* and the *Vaccination Inquirer*.[5] Propaganda was often used to visually represent and exaggerate vaccination concerns and was likely distributed in an attempt to grow the anti-vaccination movement.[6] As a result, individuals increasingly opposed and refused vaccinations, causing outbreaks to flourish. For example, the vaccination system in Stockholm broke down due to the spread of misinformation, and vaccination rates fell to roughly 40% in 1872. The rest of Sweden had a rate of roughly 90%. As such, the undervaccination led to a smallpox epidemic in 1874, which eventually resulted in widespread vaccination.[2]

In response to the emerging anti-vaccination movement, the General Board of Health, created in 1848 in Great Britain, investigated the inaccuracies of the spreading propaganda. To settle misinformation surrounding vaccinations, they released a report summarizing the responses to a questionnaire sent to over 500 physicians.[3] Another governmental response was the formation of a Royal Commission, which was appointed to examine both pro and anti-vaccination ideologies. In 1896, they declared that penalties for not vaccinating should be abolished despite the efficacy of the vaccination.[3] A new Vaccination Act in 1898 integrated this change. The Commission also introduced the *Conscience Clause* which allowed exemptions for parents who believed that vaccinations were unsafe or ineffective.[7] Overall, the smallpox anti-vaccination movement sparked the revision of multiple Vaccination Acts, which was instrumental in the development of safer vaccination procedures. Hesitancy, in the form of protests and propaganda, was met with appointed boards to weigh anti-vaccination concerns and scientific facts equally to reach conclusions that would benefit public health.

MMR VACCINE CONTROVERSY

Similar hesitancy still surrounds the MMR vaccine. Concerns arose after the 1998 publication of a research study by Dr. Andrew Wakefield that has since been retracted due to fabrication of data. Wakefield's study declared an association between the MMR vaccination and the onset of autism.[8] Apprehension about this finding spread quickly due to the extensive media coverage surrounding this study. A survey was later conducted to quantify this media coverage and researchers found that the public was misled to believe that equal evidence existed both for and against the vaccination.[9]

Certain religious groups in the U.S. are likely to oppose the vaccination and are granted "religious faith exemptions".[11] Other individuals may seek philosophical exemptions, that are not faith or group based, but rather focus on the individual's objection. However, many people have collectively formed anti-vaccination groups that believe vaccinations "are either more dangerous than clinicians will admit or somehow not conducive to the natural development of a child".[11]

Though this controversy began in 1998, its impacts are still felt today. Much like Stockholm, this anti-vaccination movement sparked a measles outbreak in 2015, in a Disneyland park in California. As the outbreak spread to multiple states, this event initiated the re-evaluation of vaccine exemptions.[11] In the United States, vaccination exemptions have led to geographical clusters of intentionally unvaccinated individuals.[12] These areas are at high-risk for outbreaks of preventable diseases like measles. Ultimately, undervaccination contributes to preventable outbreaks that put a strain on public health systems.[13]

CONCLUSION

The MMR and smallpox vaccination controversies were driven by questions surrounding vaccination efficacy, desire for autonomy and parental choice, and religious and ethical concerns. When comparing the smallpox and MMR vaccination controversies, arguments for religious beliefs and autonomy have persisted. It is evident that the nature of the media coverage and communication likely played a significant role in the outcomes of these two preventable diseases. The MMR controversy was fueled by great media attention that was not met with effective governmental response. As cases of measles persist, it is clear that governments and public health officials should focus on improving their communication methods to limit misinformation and misguided concerns. Ultimately, both examples demonstrate the need for proper science communication surrounding vaccines, as they can protect people worldwide from dangerous communicable diseases.

ACKNOWLEDGEMENTS

A special thank you to Dr. Tabitha Marshall who encouraged me to pursue further research in this field and inspired me to create this piece. This is a member contribution to Sciential. We stand by our double blind editing process and consistently ensure that our team upholds editing standards and ethics.

REFERENCES

(1) Riedel S. Edward Jenner and the History of Smallpox and Vaccination. Baylor University Medical Center Proceedings. 2005;18(1).

(2) Nelson MC, Rogers J. The right to die? Anti-vaccination activity and the 1874 smallpox epidemic in stockholm. Social History of Medicine. 1992;5(3).

(3) Dudgeon JA. Development of smallpdx vaccine in england in the eighteenth and nineteenth centuries. British Medical Journal. 1963;1(5342).

(4) Wolfe RM, Sharp LK. Anti-vaccinationists past and present. Vol. 325, British Medical Journal. 2002.

(5) Porter D, Porter R. The politics of prevention: Anti-vaccinationism and public health in nineteenth-century England. Medical History. 1988;32(3).

(6) Harris J. Rash Decisions: Anti-vaccination Movements in Historical Perspective. ORIGINS Current Events in Historical Perspective. 2019. 13(2).

(7) Williamson S. Anti-Vaccination Leagues. Vol. 59, Archives of Disease in Childhood. 1984.

(8) Wakefield AJ, Murch SH, Anthony A, Linnell J, Casson DM, Malik M, et al. Retracted: Ileal-lymphoid-nodular hyperplasia, non-specific colitis, and pervasive developmental disorder in children. Lancet. 1998;351(9103).

(9) Dobson R. Media misled the public over the MMR vaccine, study says. BMJ (Clinical research ed). 2003;326(7399).

(10) Hefferon M, Funk C. (2020, January 7). More Americans now see 'very high' preventive health benefits from measles vaccine. 2020.

(11) Bowes J. Measles, misinformation, and risk: personal belief exemptions and the MMR vaccine. Journal of Law and the Biosciences. 2016;3(3).

(12) Ernst KC, Jacobs ET. Implications of philosophical and personal belief exemptions on re-emergence of vaccine-preventable disease: The role of spatial clustering in under-vaccination. Vol. 8, Human Vaccines and Immunotherapeutics. 2012.

(13) Sugerman DE, Barskey AE, Delea MG, Ortega-Sanchez IR, Bi D, Ralston KJ, et al. Measles Outbreak in a highly vaccinated population, San Diego, 2008: Role of the intentionally undervaccinated. Pediatrics. 2010;125(4).

(14) Hilton S. Enlighten: Theses. Parental perceptions of childhood immunisation in the context of the MMR controversy, University of Glasgow, 2005;245.

ARTICLE INFORMATION

Senior Editor
Reza Khorvash

Reviewers and Section Editors
Zoya Adeel, Kushi Malhotra

Formatting and Illustrations
Angelina Lam

SCIENTIAL TEAM


Ishita Paliwal
Editor-in-Chief
Honours Integrated Science, 2021

Isabel Dewey
Editor-in-Chief
Honours Life Sciences, 2021

Reza Khorvash
Senior Editor
Honours Life Sciences, 2021

Stefano Armando Biasi
Senior Editor
Honours Life Sciences, 2022

Youssef El-Sayes
Creative Director
Honours Life Sciences, 2021

Caitlin Reintjes
Editor
Honours Integrated Science, 2021

Kasia Tywonek
Editor
Honours Integrated Science, 2021

Zoya Adeel
Editor
Honours Life Sciences, 2021

Emerald Lin
Editor
Honours Life Sciences, 2022

Kushi Malhotra
Editor
Honours Life Sciences, 2021

Naomi Suzuki
Editor
Honours Life Sciences, 2022

Dalen Koncz
Editor
Honours Life Sciences, 2022

Lavanya Sinha
Editor
Honours Life Sciences, 2023

Keerat Grewal
Editor
Honours Biochemistry, 2021

Angelina Lam
Graphic Designer
Honours Integrated Science, 2023

Danial Aminaei
Graphic Designer
Honours Life Sciences, 2021

Mahnoor Memon
Communications Coordinator
Honours Life Sciences, 2021

Simran Kaur
Illustrator
Honours Life Sciences, 2021

Roushan Tabassum
Illustrator
Honours Human Behaviour, 2021

SENIOR ADVISORS

Dr. Katie Moisse[1,3]
Dr. Kimberly Dej[1,3]
Dr. Rodriguez Moncalvo[1,3]
Abeer Siddiqui[2,3]
1. Assistant Professor
2. Learning Support Librarian
3. School of Interdisciplinary Science

CO-FOUNDERS

Alisa Nykolayeva
Co-Founder, Consultant
Honours Life Sciences, 2021

Aiman Shahid
Co-Founder, Consultant
Honours Life Sciences, 2020

CREDITS

Cover Page Illustrations: Roushan Tabassum, Simran Kaur

Layout Design: Angelina Lam, Danial Aminaei, Youssef El-Sayes

ISSN 2562-1483