

## Evaluation of a pilot paediatric concussion telemedicine programme for northern communities in Manitoba

Michael J. Ellis<sup>a,b,c,d,e,f</sup>, Susan Boles<sup>g</sup>, Vickie Derksen<sup>d</sup>, Brenda Dawyduk<sup>h</sup>, Adam Amadu<sup>h</sup>, Karen Stelmack<sup>g</sup>, Matthew Kowalchuk<sup>g</sup> and Kelly Russell<sup>b,e,f</sup>

<sup>a</sup>Department of Surgery, University of Manitoba, Canada; <sup>b</sup>Pediatrics and Child Health, University of Manitoba, Canada; <sup>c</sup>Section of Neurosurgery, University of Manitoba, Canada; <sup>d</sup>Pan Am Concussion Program, Winnipeg, Manitoba, Canada; <sup>e</sup>Childrens Hospital Research Institute of Manitoba, Winnipeg, Manitoba, Canada; <sup>f</sup>Canada North Concussion Network, Winnipeg, Manitoba, Canada; <sup>g</sup>MBTelehealth, Manitoba eHealth, Winnipeg, Manitoba, Canada; <sup>h</sup>Thompson General Hospital, Thompson, MB, Canada

### ABSTRACT

Pediatric concussion patients living in northern communities in Canada can face unique challenges accessing primary and specialized healthcare. In this study we report the clinical characteristics, healthcare utilization, outcomes and estimated cost avoidance associated with a pilot pediatric concussion telemedicine program established between a multi-disciplinary pediatric concussion program in Winnipeg, Manitoba and a hospital in Thompson, Manitoba. From October 1<sup>st</sup>– July 1<sup>st</sup>, 2018, 20 patients were evaluated; mean age 13.1 years, 15 (75%) males and 14 (70%) self-identified as Indigenous. Injury mechanisms included hockey (50%), falls (35%) and assaults (15%). Median time from referral to initial consultation was 2.0 days. After screening by the neurosurgeon, 90% of patients underwent initial consultation via real-time videoconferencing with 80% managed exclusively through telemedicine. At the end of the study, 90% met the criteria for clinical recovery, one remained in treatment and one was discharged to a headache neurologist. Sixty-six telemedicine encounters were completed including 57 videoconferencing appointments and 9 telephone follow-ups representing an estimated cost avoidance of \$40,972.94. This study suggests telemedicine may be a useful approach to assist pediatric concussion programs with delivering timely, safe and cost-effective care to patients living in medically underserved remote and northern communities in Canada.

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Concussion is a form of mild traumatic brain injury (mTBI) caused by biomechanical forces transmitted to the brain resulting in temporary alterations in neurological functioning that often resolve spontaneously [1]. In Canada, paediatric concussion and mild TBI commonly occur in the setting of sport and recreational activities but other mechanisms can include motor vehicle collisions, falls and assaults [2]. With proper medical assessment and follow-up, the majority of paediatric patients will experience complete recovery within 1 month post-injury [3]. However, patients without timely access to post-injury medical care remain at risk of additional injury associated with premature return to sports and other high-risk activities, as well as the development of persistent symptoms that can have a negative impact on mental health, school functioning and quality of life [4–7].

Children and adolescents who live in remote northern Canadian communities are among those who are potentially at an elevated risk of suffering these preventable outcomes. It is well known that people living

in northern Canadian communities, an important proportion of whom are Indigenous, face unique challenges in accessing primary and sub-specialty healthcare often as a result of geographic, cultural and socioeconomic factors [8–14]. In order to overcome these barriers, leaders in healthcare must develop novel and sustainable programmes to help deliver a high standard of safe, equitable and cost-effective care closer to the patient's home community [15].

Over the past decade, the use of provincial telemedicine programmes has emerged as an important platform to help connect Canadians living in remote, rural and northern communities with specialised healthcare services [15–19]. The World Health Organisation defines telemedicine as “the delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests

of advancing the health of individuals and their communities" [20]. Previous work has demonstrated the feasibility of using telemedicine to assist with the clinical care of patients with a wide spectrum of neurological conditions including stroke [16,21,22], headache [23–25], multiple sclerosis [26], mental health disorders [27,28], epilepsy [29,30] and neurodegenerative diseases [31–34]. Although preliminary studies have suggested that telemedicine may be helpful in providing sideline and in-office care to patients with concussion [35,36], there have been no studies that have examined the use of this technology to provide clinical care of paediatric concussion patients living in remote and medically underserved communities in northern Canada.

Here we present the initial experience of the Pan Am Clinic CONcussion in the North Education, Consultation, and Telemedicine (CONNECT) Program, a novel pilot project aimed at providing concussion education and telemedicine care to children and adolescents living in remote northern communities in the province of Manitoba. We review the development of this project and summarise the clinical findings and cost avoidance estimates from the first 9 months of this programme. We also discuss important considerations for developing telemedicine programmes that aim to care for paediatric concussion patients living in northern and remote communities in Canada.

## Methods

### *The Pan Am Concussion Program*

The Pan Am Concussion Program is provincial government-funded clinical programme in Winnipeg, MB, Canada devoted to the multi-disciplinary assessment and management of paediatric concussion and TBI. The concussion programme is a component the Pan Am Clinic, a primary care, sports medicine, and orthopaedic surgery clinic but is located off-site at the Bell MTS Iceplex, the practice facility of the Winnipeg Jets National Hockey League team [37]. The Pan Am Clinic and concussion programme operate within the Winnipeg Regional Health Authority, a government-affiliated organisation that oversees operation of publicly funded healthcare facilities within Winnipeg, MB. The paediatric concussion programme serves a geographically and ethnically diverse catchment area of approximately 1.5–2 million residents that includes the entire province of Manitoba, as well as regions of eastern Saskatchewan, northwestern Ontario, and central Nunavut. The programme receives approximately 800–900 patient referrals

per year from emergency departments, primary care providers and through direct access sport-specific youth concussion protocols. Paediatric patients ( $\leq 19$  years of age) referred to the clinic include those with sports and non-sports-related concussion and mTBI, patients with acute injuries and those with persistent post-concussion symptoms (PPCS), and patients with moderate and severe TBI requiring multi-disciplinary neuro-rehabilitation.

All patients who receive in-person care at the Pan Am Concussion Program undergo initial medical assessment by a single neurosurgeon, including administration of a validated concussion symptom inventory (Post-Concussion Symptom Scale, PCSS) [38], clinical history, comprehensive physical examination and review of relevant diagnostic tests and imaging. The physical examination includes evaluation of cranial nerve, motor, sensory and cerebellar functioning, as well as reflexes and balance testing. A focused vestibulo-ocular examination is performed including objective assessment of convergence, smooth pursuits, saccades and vestibulo-ocular reflex testing, as well as Dix-Hallpike and supine roll testing for patients with suspected post-traumatic benign paroxysmal positional vertigo. In addition, a cervical spine examination is performed including assessment of range of motion, palpation for central and paraspinal tenderness and cervical flexion testing. In general, patients with acute concussion are seen in follow-up on a weekly or bi-weekly basis depending on the rate of their recovery and are typically managed conservatively for the first 1–3 weeks with education and supervised guidance through their respective Return-to-School and sport-specific Return-to-Sport strategies where applicable. Patients who develop or initially present with PPCS are considered for further testing (i.e. graded aerobic exercise testing) or referrals to multi-disciplinary specialists to inform the development of individually tailored rehabilitation programmes targeting the pathophysiological processes responsible for persistent symptoms, including vestibulo-ocular dysfunction, cervical spine dysfunction, exercise intolerance, post-traumatic headaches or migraine headaches and post-injury mood or psychiatric disorders [39,40]. In general, patients are considered clinically recovered when they are asymptomatic or back to their pre-injury neurological status at rest, are tolerating full-time school activities without symptoms, and do not demonstrate clinical evidence of vestibulo-ocular or cervical spine dysfunction. In some patients, graded aerobic treadmill testing and/or neuropsychological testing is used to confirm clinical recovery at the discretion of the neurosurgeon. Patients

returning to sports are also required to have successfully completed their sport specific Return-to-Sport strategy [1].

Clinical care at the Pan Am Concussion Program is provided by a multi-disciplinary team of on- and off-site professionals with expertise in concussion and TBI who are funded through different sources. Medical services provided by the treating neurosurgeon are covered by provincial healthcare insurance, whereas services provided by the on-site clinical neuropsychologist are covered by provincial government programme funding. Graded aerobic exercise testing is carried out at no cost to the patient by an on-site exercise physiologist who is a salaried employee of the Pan Am Clinic Foundation, a registered charitable organisation that provides research and clinical support to the Pan Am Clinic. Referrals to off-site multi-disciplinary experts in vestibular and cervical spine physiotherapy, headache neurology, neuro-ophthalmology, neuro-radiology, adolescent psychiatry and sports medicine are made by the neurosurgeon on an as needed basis. Similar to the neurosurgeon, services provided by consulting physicians are covered by provincial healthcare insurance whereas services provided by physiotherapists are covered by third party insurance or are billed privately to the patient or their parents. Diagnostic tests, including diagnostic imaging, electrophysiological testing and blood work performed at hospitals within the province of Manitoba are also covered by provincial healthcare insurance.

### **Pan Am Clinic CONNECT Program**

The overall objective of the Pan Am Clinic CONNECT Program was to optimise the care of northern paediatric concussion patients through a novel and collaborative education and consultation service developed in partnership by the Pan Am Concussion Program, Winnipeg Regional Health Authority, Northern Health Region and MBTelehealth. The rationale for developing the Pan Am Clinic CONNECT Program arose as a consequence of several factors. First, a small but important proportion of Pan Am Concussion Program patients are from remote northern communities and are required to travel great distances, often by air and requiring overnight accommodations, in order to receive comprehensive care that is not available in their communities. Second, many northern communities in Manitoba have limited or inconsistent access to primary healthcare providers with experience managing paediatric concussion and TBI patients. Lastly, in May 2017 the Manitoba provincial government tabled *The Concussion in Youth Sport Act*, a bill that would

apply to all provincial youth sport organisations and schools and mandate the development of concussion protocols that would require all sport stakeholders, including athletes, parents, coaches and teachers to undergo annual concussion education; require all youth athletes who sustained a suspected concussion during a sport activity to be immediately removed from play; and require all youth athletes with suspected concussion to undergo assessment and clearance by a medical doctor, nurse practitioner, physician assistant (or nurse under the supervision of a consulting medical doctor or nurse practitioner) prior to returning to sports [41]. Taken together, these circumstances lead health-care stakeholders to examine potential measures that could be taken to ensure that all Manitoba youth had timely and equitable access to high-quality concussion care close to their home communities. Thus, we initiated the Pan Am Clinic CONNECT Program as a pilot project to meet two key objectives: (1) provide concussion education to youth, teachers, sport stakeholders and medical professionals living in a pre-selected northern Manitoba community and (2) establish a telemedicine consultation service that would help support the medical management of paediatric concussion patients in this region.

The first site that was chosen for this pilot project was Thompson, MB. Thompson is the fourth largest city in Manitoba with a population of approximately 13,000 residents, serves as a regional service and industrial centre for northern Manitoba and is located approximately 760 km from Winnipeg. Surrounded by a number of smaller Indigenous communities and reserves, approximately 43% of Thompson residents self-identify as Indigenous including 32% who identify as First Nations and 11% who identify as Metis [42]. Thompson has one high school for grade 9–12 students (R.D Parker Collegiate) and is home to the Thompson Minor Hockey Association that oversees organised youth hockey in the city. Medical facilities include one community hospital (Thompson General Hospital) that provides emergency and tertiary care services for the city and surrounding region, a primary care clinic, and Hope North Recovery Centre For Youth, a six-bed mental health and addictions stabilisation unit that also serves as the home of the region's mobile crisis and mental health outreach services. Primary paediatric care for Thompson, MB and the larger surrounding region is provided by a nurse practitioner and 1–2 paediatricians. Most residents of Thompson who require consultation or follow-up care with medical specialists are required to travel to Winnipeg, MB by car (a 8–10 h drive depending on seasonal road conditions) or by airplane (a 1.5 h flight). However, some medical specialty services (i.e.

ophthalmology, psychiatry, medical genetics, endocrinology) are available through a well-established telemedicine site located at the Thompson General Hospital.

To provide community and healthcare professional concussion education, a team of stakeholders from the Pan Am Concussion Program, Children's Hospital Research Institute of Manitoba, Sport Manitoba and the Winnipeg Jets True North Foundation travelled to Thompson. On 14 September 2017, the team provided in-person outreach presentations on youth concussion and mental health to students at R.D. Parker Collegiate and community sport stakeholders including parents and coaches. Teachers at the high school were provided an in-person presentation on concussion, the effects of concussion on school functioning and academic accommodations that could be helpful in optimising a successful return to the classroom following concussion. Lastly, community healthcare professionals were provided with an in-person and video-linked presentation on the assessment and management of acute concussion in children and adolescents.

Following this education initiative a telemedicine consultation service for paediatric concussion patients was established between the Thompson General Hospital and the Pan Am Concussion Program through MBTelehealth. MBTelehealth is a government-funded programme affiliated with Manitoba eHealth that facilitates and coordinates telemedicine services for the province of Manitoba. The telemedicine site in Thompson is among the highest volume telemedicine sites in the province and is uniquely positioned with full-time staff to help coordinate telemedicine appointments on a daily basis and dedicated videoconferencing rooms. In contrast, many telemedicine sites in Manitoba do not have full-time staff to coordinate appointments on a daily basis and conduct videoconferencing sessions in medical examination rooms that are regularly used for other purposes at these facilities. Taken together, Thompson's overburdened and inconsistent access to paediatric primary care but strong access to emergency medicine and telemedicine services made it the ideal site for our pilot paediatric concussion telemedicine programme.

The collaborative paediatric concussion telemedicine pilot project ran from 1 October 2017 to 1 July 2018. During this time period, emergency medicine physicians and primary care providers had the option of managing patients independently or could refer patients for consultation and follow-up through the telemedicine programme at their own discretion and based on available healthcare resources. Using a standardised referral form posted on the Pan Am Concussion Program website, emergency medicine

and primary care providers in Thompson were able to refer paediatric patients ( $\leq 19$  years of age) with suspected or diagnosed acute concussions/head injuries, as well as those with PPCS. Due to the limitations of performing a complete neurological and cervical spine examination during telemedicine consultations, all patients referred through the paediatric concussion telemedicine programme were required to undergo initial medical assessment, including clinical (and as needed radiological) exclusion of a more severe TBI or associated cervical spine injury by the referring physician or nurse practitioner. All referrals were received by the Pan Am Concussion Program and reviewed by a single neurosurgeon to determine whether initial consultation could be safely conducted through real-time videoconferencing or whether the injury and clinical details warranted travel to Winnipeg for in-person consultation. To facilitate timely scheduling of initial consultations, as well as follow-up appointments, both sites arranged to schedule all appointments during reserved time slots on Wednesday afternoons. As such, patients who were eligible for initial consultation through videoconferencing had appointments scheduled on the first Wednesday following receipt and review of the patient referral unless the patient or their parents chose to schedule the appointment on an alternative date. Patients selected for in-person consultation had appointments scheduled as soon as the patient and their parents could arrange appropriate travel to Winnipeg.

Prior to each initial real-time videoconferencing appointment, patients and their parents presented to an MBTelehealth site and underwent registration and confirmation of their identity by local site support staff and completed the concussion symptom inventory. Prior to each appointment the neurosurgeon reviewed any previously arranged diagnostic imaging studies completed at Thompson General Hospital or Health Sciences Centre- Children's Hospital through a shared Manitoba eHealth picture archiving and communication (PACS) system. All real-time videoconferencing appointments were carried out between patients and the treating neurosurgeon using a software-based telemedicine platform (Cisco Jabber) that met provincial and institutional personal health information and privacy requirements. The neurosurgeon logged into a MB eHealth secured laptop computer with built-in web camera that allowed him to interface with the patient and their parents who were seated in an examining room with a wall mounted television monitor. Initial real-time videoconferencing consultations included a complete clinical history, as well as non-standardised physical examination. Because the videoconferencing

appointments were completed without the presence of a trained telepresenter, the physical examination was limited to components that did not require physical contact with the patients, such as assessment of gross extra-ocular movements, facial symmetry, tongue movement, pronator drift, cervical spine range of motion, symptom provocation during horizontal, vertical saccade and head shaking movements, balance testing and 5-word immediate and delayed recall. Following initial consultation, patients were provided with a post-concussion education package and those who sustained sports-related concussions received a *Canadian Guideline on Concussion in Sport Medical Assessment or Clearance Letter* that provided information regarding what activities the patient was medically cleared to return to and how to make a gradual return to school and sport activities [43]. The medical clearance letters were signed by the neurosurgeon, faxed to the distant telemedicine site and given to the patient or their parents by the site facilitator.

Following initial consultation, patients were scheduled for weekly or bi-weekly follow-up appointments depending on the trajectory of their clinical recovery. Whenever possible, follow-up clinical care was carried out using real-time videoconferencing. However in select cases, patients were considered for in-person assessment if, in the neurosurgeon's opinion, they required a more complete physical examination, referral to another member of the multi-disciplinary team, or diagnostic testing that was not available in the patient's home community. In these cases, all specialist appointments and tests were arranged for the same day or trip to Winnipeg whenever possible. In select patients who did not live in Thompson and were required to travel considerable distances for in-person videoconferencing follow-up appointments, the patients and parents were given the opportunity to follow-up by telephone. On occasion, patients who did not want to miss school for select in-person videoconferencing follow-up appointments also underwent telephone follow-up. Patients evaluated through the telemedicine programme were considered clinically recovered when they were asymptomatic or back to their pre-injury neurological status at rest according to symptom inventory and/or clinical interview, were tolerating full-time school activities without symptoms, and had successfully completed their sport specific Return-to-Sport strategy where applicable. As part of the pilot project, patients who were clinically recovered and discharged from care also underwent a delayed follow-up telephone call approximately 1 month or more post-injury to assess whether the patient had sustained a repeat concussion or experienced any recurrent concussion symptoms.

All medical records collected from in-person and telemedicine appointments were stored in secured paper and electronic forms at the Pan Am Concussion Program according to institutional personal health information and privacy requirements. Because the telemedicine programme used existing regional health authority and clinic infrastructure and resources, there were no capital costs associated with establishing the paediatric concussion telemedicine programme.

### **Study design and analysis**

We performed a retrospective chart review of all consecutive patients who underwent initial assessment and clinical care through the paediatric telemedicine programme from 1 October 2017 to 1 July 2018. Patients included in the study were (1) 19 years or younger; (2) diagnosed with an acute concussion, head injury or PPCS; and (3) underwent at least one appointment via our telemedicine programme. Patients were diagnosed with an acute concussion if they met the diagnostic criteria set forth by the 5th International Consensus Statement on Concussion in Sport [1] and underwent clinical consultation within 4 weeks post-injury. Patients were diagnosed with PPCS if they met the diagnostic criteria for a concussion and had symptoms that persisted greater than 4 weeks post-injury [3]. Patients who sustained a traumatic impact to the head but were too young to provide a clinical history consistent with the diagnosis of concussion were diagnosed with head injuries. Clinical data related to patient demographics, injury characteristics, outcomes and healthcare utilisation was presented as medians, interquartile ranges and ranges where appropriate.

In order to provide an estimate of the cost avoidance for this pilot project, we conducted an analysis of the travel costs had the patients travelled to Winnipeg to attend in-person care instead of travelling to their appropriate telemedicine site. Estimated travel costs were calculated using the Winnipeg Regional Health Authority road travel reimbursement rates of \$0.41 per km travelled. These calculations did not include costs associated with air travel for patients living in communities that are not accessible by road (e.g. Churchill, MB). Delayed telephone follow-up appointments were also not included in this analysis since these were conducted for quality assurance purposes. Institutional ethics approval for this study was obtained from the University of Manitoba and the Winnipeg Regional Health Authority.

### **Results**

During the study period, 20 patients underwent initial assessment and management through the paediatric



telemedicine programme. The mean age of the patients was 13.1 years (SD 4.6; range 1.8–17) and 15 (75%) were males. At the time of referral, 16 were living in Thompson, MB while 4 were living in other smaller northern Manitoba communities. Fourteen patients (70%) self-identified as Indigenous. Past medical history was notable for previous concussion (6; 30%), depression (2; 10%), anxiety (1, 5%) and attention deficit hyperactivity disorder (1; 5%). Mechanisms of injury included hockey (10; 50%), falls (7; 35%) and assaults (3; 15%).

Among the 20 patients evaluated through the paediatric telemedicine programme, 16 (80%) were referred by the emergency department at Thompson General Hospital, 3 (15%) were referred by primary care providers in Thompson, MB and 1 (5%) was referred by the emergency department at Health Sciences Centre – Children’s Hospital in Winnipeg, MB. Of the 20 patients, 18/20 (90%) underwent initial assessment through telemedicine videoconferencing. Two patients underwent in-person initial consultation at the multi-disciplinary concussion programme including one who underwent initial assessment at Health Sciences Centre – Children’s Hospital in Winnipeg and underwent initial consultation at the concussion programme 2 days later and prior to returning to their remote home community. The other patient was initially evaluated in Thompson but was selected to undergo in-person initial consultation at the concussion programme due to a clinical history of monocular visual symptoms and neuroimaging evidence of an orbital floor fracture. Overall, the median time from injury to referral to the multi-disciplinary concussion programme was 3.5 days (interquartile range 1.75, 10), the median time from the date the referral was received and reviewed at the concussion programme to the date of initial consultation with the neurosurgeon was 2 days (interquartile range 1, 6.25) and the median time from injury to initial consultation with the neurosurgeon was 10 days (interquartile range 4.75, 14.75). Diagnostic tests arranged prior to consultation with the neurosurgeon included CT-imaging of the brain (5 patients); CT-imaging of the cervical spine (1 patient); plain radiographs of the spine (2 patients); electrocardiography (1 patient); and electroencephalography (1 patient).

The median PCSS score among the 18 child and adolescent patients who completed this measure at initial consultation with the neurosurgeon was 20.5 (interquartile range 5.75, 26.75). Following initial consultation, 17 (85%) were diagnosed with an acute concussion, 1 (5%) was diagnosed with PPCS and post-traumatic migraine headaches and 2 infants were diagnosed with head injuries. One patient with an acute concussion and orbital floor fracture underwent same-

day in-person initial consultation with the neurosurgeon and a neuro-ophthalmologist resulting in an additional diagnosis of an inferior oblique extraocular muscle entrapment. During clinical care of this patient cohort, referral to other multi-disciplinary experts were arranged for four (20%) patients including referrals to a headache neurologist (two patients), vestibular physiotherapist (one patient), neuro-ophthalmologist (two patients), paediatric ophthalmologist (one patient), plastic surgeon (one patient), mobile crisis and an adolescent psychiatrist (one patient), and an exercise physiologist for graded aerobic treadmill testing (one patient). Following clinical consultation with the neurosurgeon only one patient required additional diagnostic tests that included an MRI of the brain to investigate persistent headaches and visual disturbance that was normal. Interventions or treatments initiated in this patient cohort included a home vestibular physiotherapy programme (one patient), pharmacological treatment of headaches (two patients), sub-maximal aerobic exercise prescription (one patient) and re-institution of pharmacological treatment for pre-existing depression and sleep disturbance (one patient).

By the end of the study period, 18 (90%) patients met the criteria for clinical recovery, one remained in treatment and one was discharged to the care of the headache neurologist. One patient was initially lost to follow-up but was eventually contacted by telephone and found to be symptom-free; however, an exact date of recovery could not be determined for this patient. The median time from injury to clinical recovery among those who achieved physician-documented clinical recovery was 25 days (15.75, 42.25 days). During this study period, 66 telemedicine encounters were completed including 57 videoconferencing appointments and 9 telephone follow-ups. The median number of telemedicine encounters utilised per patient was 2 (interquartile range 2, 3.25). All patients underwent videoconferencing appointments in Thompson with the exception of one patient who underwent in-person initial consultation in Winnipeg but underwent two follow-up videoconferencing appointments in Churchill, MB. Overall, 16/20 (80%) patients included in the study were managed exclusively through telemedicine. One patient was managed clinically through telemedicine; however, after achieving clinical recovery travelled to Winnipeg, MB for a previously arranged EEG. Of the 16 patients who achieved clinical recovery and underwent delayed telephone follow-up, none reported experiencing any repeat concussions or recurrent post-concussion symptoms.

The estimated cost avoidance associated with the 66 telemedicine encounters conducted during this pilot

study was \$40,972.94 or \$2048.65 per patient. The estimated cost associated with the nine trips to Winnipeg taken among three patients who required in-person assessments was \$5616.18.

## Discussion

To our knowledge, this is the first study to examine the feasibility of using telemedicine to provide clinical care to paediatric concussion patients living in remote and medically underserved communities in northern Canada.

In this pilot study of a novel telemedicine programme established between a multi-disciplinary paediatric concussion programme and a hospital located in a remote northern Manitoba community, 20 patients with concussion or head injury received timely access to specialised concussion care and follow-up that was otherwise not available in their community. After appropriate screening by a neurosurgeon, 90% of patients in this cohort underwent initial consultation via real-time videoconferencing with 80% managed exclusively through telemedicine. At the discretion of the neurosurgeon, three patients were required to undergo in-person consultation or follow-up appointments in order to facilitate a more comprehensive physical examination and/or referral to other multi-disciplinary professionals to further investigate and manage more worrisome or persistent post-concussion symptoms. Among those that achieved physician-documented clinical recovery and underwent delayed telephone follow-up, none reported experiencing any recurrent concussions or post-concussion symptoms in the first month after discharge from the telemedicine programme. Furthermore, our analysis suggested an overall cost avoidance of \$40,972.94 compared to care that would have been received had the patients and their parents travelled to the paediatric concussion programme to attend the same quantity of visits in-person. Overall, the standard of care received by patients managed through the telemedicine in this study compares favourably to that provided to local patients managed through our multi-disciplinary paediatric concussion programme. Indeed, patients with acute sports-related concussion who receive in-person care through our paediatric concussion programme undergo initial consultation a median of 7 days post-injury, are managed by the same neurosurgeon and multi-disciplinary team, and achieve a complete clinical recovery in 82% of cases with a median length of recovery of 23 days [37]. Despite these encouraging initial results, this study identified several key limitations and considerations that healthcare stakeholders must be aware of in order to optimise the safety, quality of care and cost-efficiency of these programmes.

Perhaps the most important limitation of using telemedicine to deliver consultative services to patients with neurological disorders is the inability of the remote consulting physician to conduct a complete neurological examination. The diagnosis of acute concussion requires a physician to reliably exclude more serious forms of TBI, as well as structural injury to the cervical spine, which can only be accomplished through a careful history, focused physical examination and the evidence-based use of diagnostic imaging [43]. Although some authors have demonstrated the feasibility and reliability of using abbreviated concussion screening tools, such as the Sport Concussion Assessment Tool (SCAT) and King–Devick Test via telemedicine videoconferencing [35,36], several essential aspects of the neurological examination including testing of motor and sensory functioning, tone, reflexes and fundoscopy can not be performed unless another trained clinician is available to conduct these tests and present the findings to the remote consulting physician [44,45]. Subtle signs appreciated during objective assessment of oculomotor, vestibular and cervical spine function can be helpful in guiding clinical decisions regarding the need for diagnostic imaging and targeted rehabilitation but are also challenging or impossible to elicit during telemedicine consultations [46–48]. Given these important limitations, we believe that the use of telemedicine to manage concussion patients should be used judiciously and only offered to remote communities with limited access to primary care providers and where there are clear logistical and economic obstacles to transferring patients to distant sites for more specialised medical assessment and care. In cases where acute concussion patients are considered for management through telemedicine programmes, it is ideal that all undergo an initial in-person medical assessment and physical examination by a physician or nurse practitioner prior to referral and that the remote consulting physician have a low threshold to request an in-person assessment should they feel that additional aspects of the physical examination or adjunctive testing (i.e. grade aerobic treadmill testing, neuropsychological testing) are required to optimise patient care. It must be acknowledged, however, that some northern Canadian communities are served by nursing stations and do not have access to physicians and nurse practitioners. Therefore, future work is needed to explore how concussion telemedicine programmes can be expanded to deliver care to these more underserved communities.

Similar to our previous work, this study demonstrates that comprehensive management of paediatric concussion patients requires timely access to diagnostic

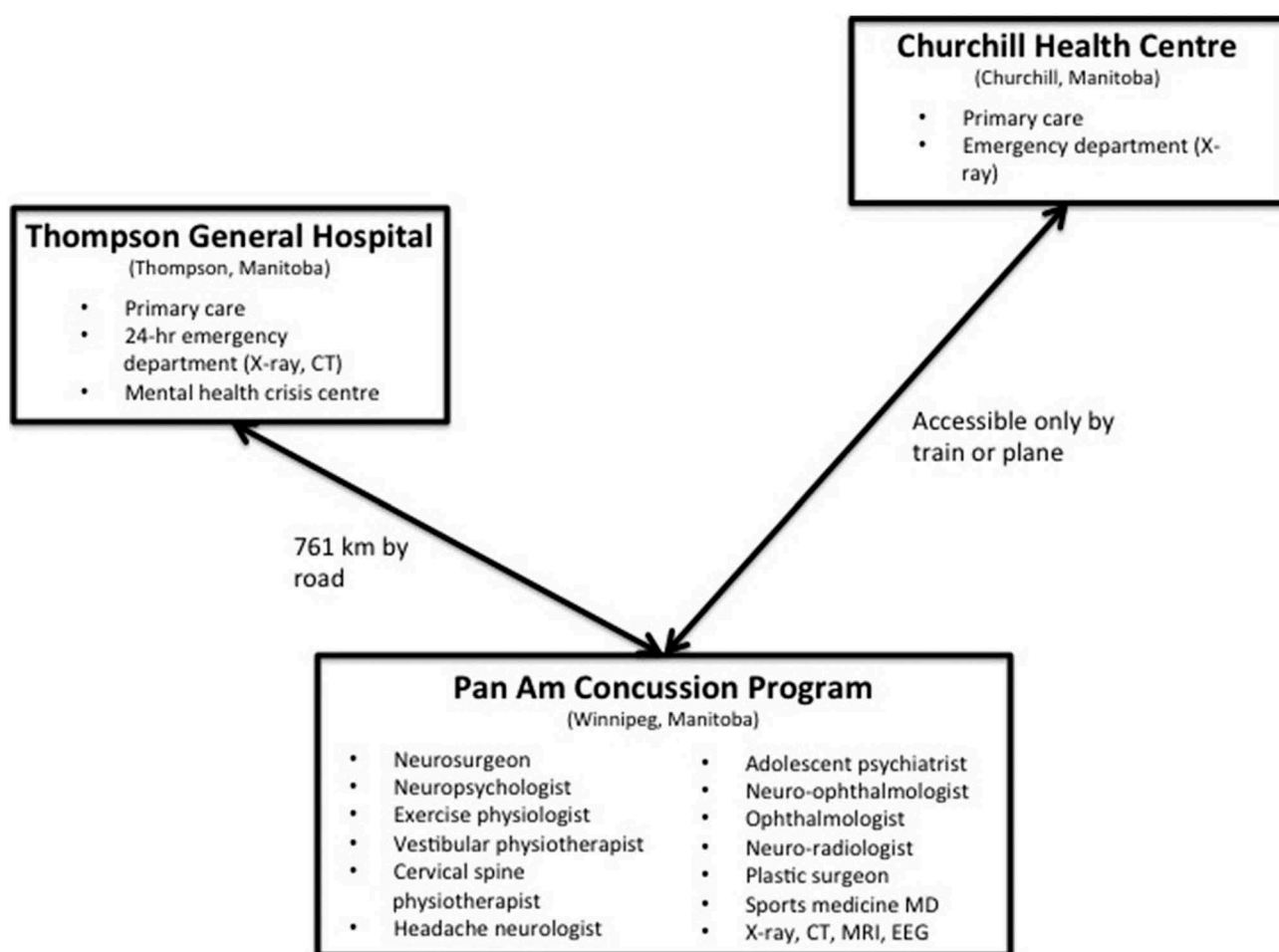
tests and a team of multi-disciplinary experts with licensed training in a variety of TBI-related sub-disciplines [4,37,39,40,49–51]. Although the majority of patients evaluated through the telemedicine programme were managed independently by the treating neurosurgeon, several benefitted from timely access to diagnostic tests and coordinated referrals to multi-disciplinary professionals who were not available within their home community. These included one patient who was diagnosed with an inferior oblique extraocular muscle entrapment secondary to an orbital floor fracture and underwent consultation with neuro-ophthalmology, ophthalmology and plastic surgery. One patient with PPCS underwent an MRI of the brain and in-person assessments with a vestibular physiotherapist, neuro-ophthalmologist, exercise physiologist and headache neurologist. One patient with post-traumatic migraines underwent in-person assessment with a headache neurologist. In addition, one patient also benefitted from timely referral to local emergency mental health services and consultation with an adolescent psychiatrist. In order to optimise the care of patients across vast geographic regions, some authors have proposed a “hub-and-spoke” or distributed model of care whereby centres with specialised expertise and resources are linked to other smaller regions centres through telemedicine-based referral pathways [44,45]. This approach has been successfully applied to disorders, such as stroke [52] and paediatric headache [23], and may be a cost-effective model for provincial paediatric concussion programmes to incorporate especially where telemedicine sites require shared access to technological infrastructure and resources and where clinically indicated diagnostic tests and in-person sub-specialist consultations can be coordinated during the same visits to these centres (see Figure 1). In addition to facilitating initial assessments and follow-up appointments, recent studies suggest that other aspects of concussion care, such as psychiatric assessment and psychotherapy, follow-up for headache management, as well as cognitive rehabilitation can also be provided through telemedicine [53], thereby presenting additional potential opportunities to reduce travel costs for patients living in rural and remote communities.

Also as demonstrated in this study, clinicians aiming to establish telemedicine concussion programmes for northern regions of Canada must give careful consideration to the unique cultural, social and economic factors that can impact care of patients living in these communities. Previous work has suggested that the disparities in health that exist among Indigenous and non-Indigenous populations are mediated by several factors including income, education, employment,

living conditions, social support and access to healthcare services [9,54]. Even where healthcare services and programmes can be made more readily available within neighbouring communities, factors, such as communication barriers, travel costs, the need to take time off work or arrange childcare, access to personal transportation, winter road conditions and previous negative or traumatic experiences with the healthcare system can present additional obstacles to receiving appropriate care and optimising patient outcomes [8,10–12,15]. Although preliminary work suggests that Canadian Indigenous populations may be at greater risk of TBI compared to non-Indigenous populations [55], there is limited data regarding the clinical characteristics, healthcare needs and long-term outcomes among Indigenous youth who sustain concussion and mTBI [56]. Clinicians caring for patients from northern Canadian communities must be aware that some Indigenous populations have their own unique approaches to health and well being that focuses on elements of physical, emotional, mental and psychological functioning and where traditional healing practices can include consultation with Elders, as well as ceremonies, public gatherings or rituals [54]. It must also be recognised that some components of multi-disciplinary concussion care, such as high-quality vestibular and cervical physiotherapy and formal neuropsychological testing may not be affordable for some patients living in remote and northern communities who do not have private healthcare insurance or are seeking care outside publically funded concussion programmes. Taken together, there is an urgent need for collaborative research to examine how the social determinants of health impact the lived experiences and outcomes of northern and Indigenous youth with concussion and how multi-disciplinary paediatric concussion programmes can tailor telemedicine programmes to deliver accessible, affordable and culturally safe concussion care to these unique patient populations. Such research will also play an important role in the development of much needed culturally specific education resources and injury prevention initiatives that can further decrease the burden of concussion and TBI among Canada’s First Nation, Metis and Inuit youth [57,58].

The results of this study should be interpreted in light of several important limitations. First, this study included a relatively small cohort of paediatric concussion patients, most of who lived in a relatively large northern Manitoba community with a hospital. This hospital has a 24-hour accessible emergency department with diagnostic imaging capabilities, a well staffed and high-volume telemedicine site, and a mental health crisis centre. Further





**Figure 1.** Diagram of the proposed “hub-and-spoke” model of paediatric concussion telemedicine care for the province of Manitoba. In the present study, the Pan Am Concussion Program (the hub) provided access to specialised paediatric concussion care through an established telemedicine network including distant sites in Thompson and Churchill, Manitoba (the spokes). CT = computerised tomography; MRI = magnetic resonance imaging; EEG = electroencephalography; MD = medical doctor.

studies are needed to establish whether the paediatric concussion telemedicine programme can be safely expanded to smaller northern communities with poorer access to emergency medicine and primary care services and telemedicine sites that do not have access to a full-time facilitator to assist with patient scheduling and technological assistance. Indeed, the authors have recently expanded this programme to the town of Churchill, MB. Churchill has a population of approximately 600 residents, is accessible only by plane or train and has a hospital without a 24-hour emergency department and a telemedicine site without a full-time facilitator. Other sites that are being considered for inclusion in this telemedicine network include Norway House, MB and Rankin Inlet, Nunavut. Second, as mentioned above, it is important that telemedicine programmes serving northern and Indigenous populations obtain patient and parent perspectives on their experiences with this technology and whether they felt the post-concussion resources provided

were sensitive to their cultural beliefs and values. Patient and parental feedback was not obtained during this study and will be considered in future studies. Lastly, the cost avoidance analysis performed in this study was conservatively based on regional health authority road travel reimbursement rates and estimated road travel distances between the patient’s place of residence and the paediatric concussion programme. These estimates did not take into consideration costs related to accommodations, food, income lost due to missed work, childcare expenses, or costs associated with airplane travel for those patients living in communities that are not accessible by road. Therefore, future studies should consider these important factors when aiming to provide a comprehensive assessment of the cost-effectiveness of these programmes.

In summary, the results of this pilot study suggest that telemedicine may be a helpful tool to assist multi-disciplinary concussion programmes in delivering timely, safe, and cost-effective care to paediatric

concussion patients living in remote and medically underserved northern communities in Canada. Given the limitations in completing a comprehensive neurological examination, we recommend telemedicine only be considered for patients with clear geographic and economic barriers to arranging in-person longitudinal assessment and follow-up. Future studies are needed to assess whether paediatric concussion telemedicine programmes can provide sustainable care across more diverse northern and circumpolar regions of Canada. These programmes will also benefit from additional research examining the impact of cultural, social and economic factors on the lived experiences, clinical outcomes and healthcare needs of northern and Indigenous youth with concussion and TBI.

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## Authors and contributions

Dr. Russell and Ellis conceptualised and designed the study, carried out the data collection and analysis, drafted the initial manuscript, critically reviewed and revised the manuscript, and approved the final manuscript as submitted. Ms. Boles, Derksen, Dawyduk, Stelmack, Mr. Kowalchuk, and Dr. Amadu assisted with data collection and analysis, critically reviewed and revised the manuscript, and approved the final manuscript as submitted. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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