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System Dynamics to Investigate Opioid Use and Chiropractic Care for Chronic Musculoskeletal Pain

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ABSTRACT

Objective: The purpose of this investigation was to create a system dynamics (SD) model, including published data and required assumptions, as a tool for future research identifying the role of chiropractic care in the management of chronic, nonmalignant pain in a Canadian population.

Methods: We present an illustrative case description of how we evaluated the feasibility of conducting a large-scale clinical trial to assess the impact of chiropractic care in mitigating excessive opioid use in Canada. We applied SD modeling using current evidence and key assumptions where such evidence was lacking. Modeling outcomes were highlighted to determine which potential factors were necessary to account for compelling study designs.

Results: Results suggest that a future clinical study diverting patients with nonmalignant musculoskeletal pain early to the chiropractic stream of care could be most effective. System dynamics modeling also highlighted design challenges resulting from unresearched assumptions that needed to be proxied for model completion. Assumptions included changing rates in opioid-associated deaths and rates of success in treatment management of addicted patients.

Conclusion: In this case, SD modeling identified current research gaps and strong contenders for appropriate follow-up questions in a clinical research domain, namely the role of chiropractic care in the management of chronic, nonmalignant pain in a Canadian population. (J Manipulative Physiol Ther 2019;xx:1-xxx)

Key Indexing Terms: *Chronic Pain; Musculoskeletal Pain; Pain Management; Chiropractic; Opioid-Related Disorders*

INTRODUCTION

Scientific inquiry extends from the judicious use of a research agenda based on the best available information. Each question in the agenda depends on complex factors such as the current body of evidence, the context within which knowledge resides, and the identification of gaps. Systematic and scoping reviews of the literature have been used to explore these factors.

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Systematic reviews are hampered when broad questions are asked within a complex domain of knowledge involving multiple underlying assumptions.[1,2] In an attempt to address this complexity, more emphasis has recently been placed on including qualitative research in the systematic review process[3] and promoting methods to acknowledge and include publication bias when providing results.[4] Unfortunately, concrete methods for appropriately managing these processes are lacking.[1,3] As a result, those interested in moving a research agenda forward may retain an incomplete view of how to progress.

Scoping reviews have been considered another means by which research may be contextualized to drive priorities within both a governmental policy framework and for stakeholder contributions.[5,6] They may be conducted before the initiation of a systematic review or a research study to characterize the suitability of a domain of knowledge and to identify current research gaps.[6-9] Despite an increasing trend toward conducting these investigations, Tricco et al[6] recently pointed out that both the conduct and the reporting of scoping reviews remains inconsistent, thus limiting their value for informing a future study.

Although systematic and scoping reviews remain important to the investigative sciences, a potential solution to the challenge of coalescing research to identify, prioritize, and manage knowledge gaps is system dynamics (SD) modeling. System dynamics is defined by the use of mathematics in representing behavior and emphasizing associated feedback loops.[10,11] As a very simple example of a feedback loop, it is understood that as births increase, so does the population; but it is also true that as the population increases so too do the number of births. In SD models, populations are considered to be stocks, meaning that their quantity is determined by accumulating their net changes over time. Each stock has an initial quantity at the start of the period of interest. Then, period by period, the net change in the stock is determined and added to (or subtracted from) its quantity from the prior period. Frequently, increases and decreases are calculated separately and referred to as the inflow to the stock and the outflow from the stock, respectively. Often these stocks and flows are physical, such as people flowing (moving) from one stock to another. They can also be intangible, such as stress or risk. System dynamics models also depict the causal links between variables, which facilities the identification of feedback loops.

The value of SD modeling in health care has been highlighted by authors such as Homer and Hirsch[12] and has typically been related to the epidemiology of disease dissemination and prevention. Our work posits the notion that SD has intrinsic value in providing much-needed clarity around the assumptions and context of complex health concerns and preparation for proposed next-step research questions.

Musculoskeletal pain, particularly chronic low-back pain, is a major variable in the use and abuse of opioids, with abuse resulting in opioid use disorder (OUD).[13,14] Chiropractic care has been shown to be of value in providing drug-free relief.[15-19] However, no specific clinical trial has been conducted to assess the impact of chiropractic care on opioid use in chronic musculoskeletal pain. We present an illustrative case study wherein we adapt an SD model of opioid use and abuse by Wakeland and his team[20-22] to include chiropractic care for the management of chronic, nonmalignant pain in a Canadian population. The model uses published data and sheds light on current assumptions. This model examines the feasibility of a large-scale clinical trial evaluating the impact of chiropractic care for musculoskeletal pain intended to mitigate excessive opioid use, and the potential factors necessary to account for a compelling study design.

Furthermore, variables requiring assumed data to initiate the model could be considered focused areas for furthering the research agenda in opioid use and abuse research. Variables in the model that have a high impact on outcome (levers) could thereafter be used to create large-scale investigations intended to affect policy.

The purpose of this investigation was to create an SD model, including published data and required assumptions, as a tool for future research identifying the role of chiropractic care in the management of chronic, nonmalignant pain in a Canadian population.

Methods

We developed an SD model representing the populations of patients receiving chiropractic therapy, opioid therapy, both therapies, and those who received opioid therapy and developed OUD. The approach used in SD is to portray models qualitatively as diagrams and quantitatively as a set of first-order, ordinary, differential equations with respect to time. These equations are solved (integrated) numerically to calculate the time trajectories, namely stocks, flows, and nonstock variables (calculated by simple algebraic equations such as ratios, products, and differences). System dynamics analysts design their models to start with the state of the system at an earlier point and to endogenously calculate the state of the system as it changes through time up to the present. If the model is able to create present time trajectories that are similar to the historical data, the method then presumes that continuing the calculations into the future can provide a plausible baseline of behavioral change that can be used to analyze the impact of possible policy directives.

The word *endogenous* is key and means that the internal logic of the model drives the primary behavior rather than external disturbances. The model represents a working theory of how the historical behavior of interest came to be. A stock is represented by its name enclosed in a rectangular box. A flow is represented by double arrow on which an hourglass-like symbol is superimposed. Its name is located near the hourglass. Causal connections are indicated by single arrows. A cloud-like symbol at the start or end of a flow represents a model boundary. For example, people with pain symptoms who are not being treated are not in the model. They flow into the model from a cloud to a stock when they begin treatment. The software used in this study, Vensim (www.vensim.com), is available for free as a personal learning edition and with additional features as Vensim Pro (Ventana Systems Inc, Vensim, Harvard, Massachusetts).

Canadian population-based data were retrieved from online nationwide statistical sources and published literature.[23-25] The original medical opioid model from Wakeland and his team was adapted for this research.[22] This is a current standard model for opioid use and abuse in pain management.[14] It already has accepted model boundaries, including the lags and nonlinearities of prescription opioid use. Therefore, we adapted this standard model to include a test of chiropractic care for prevention of opioid use in musculoskeletal pain. Adaptations included removal of nonprescription opioid abuse and removal of the discrimination between short-acting and long-acting opioid prescription behaviors. However, analysis indicated that

Table 1. *Inputs and Rates, Support, and Assumptions Associated With Model.*

Inputs and Rates	Value (people/(people × year)) Unless Noted	Support	Comment
All-cause mortality	.008	Statistics Canada[25]	
Base add opioid rate	0.125	Assumed	
Base chiro rate	0.125	Imputed from Hart[27]	25% of patients with chronic pain seek care from chiropractors. We assume about half are opioid naïve, and half take opioids for pain.
Base risk factor	1.06 (dml)	Derived through calibration	Used to force response to risk to initialize to 1
Canadian population	2.93021e + 007 × ((1.01011)^(ramp (1, initial time, final time))) people	Estimated from the Canadian Census[24]	
Chiro drop rate	0.5	Assumed	The chiropractic drop rate among patients receiving both chiropractic and opioids
Chiro failure rate	0.6	Includes patients with nerve root entrapment and central stenosis[28]	The chiropractic drop rate among people receiving *only* chiropractic care
Chiro success rate	0.4	Includes patients with nerve root entrapment and central stenosis[28]	
Co-treated dependence rate	.0007	Assumed	Assumption of substantially lower risk among patients receiving low doses supported by Chou et al[29]
Chronic pain diagnosis rate	0.088	WHO[30]	
Med-high dose overdose rate	.000143	Gomes et al[23]	
Low-dose opioid death increase factor	6 (dml)	Assumed	
Low-dose overdose rate	0.000715	Imputed from Gomes et al[23]	People at high risk of opioid overdose are 1.7× to 4.3× more likely to overdose than people getting low doses
Opioid death increase factor	20.5 (dml)	Assumed	
Opioid weaning time	1.5 y	Regier[31]	From opioid tapering physician guidelines
Percent weaned retained in chiro	90%	Assumed	Among people seeing a chiropractor and weaning off opioids
Rate of dependence	.045	Chou et al[29]	
Rate of success of chiro when offered (to people with dependence and CNMP)	0.05	Assumed	
Table function for base prescription rate	(0.05-0.25)	Wakeland et al[21]	
Years in opioid treatment	7 y	Fleming et al[32]	

CNMP, chronic nonmalignant pain.

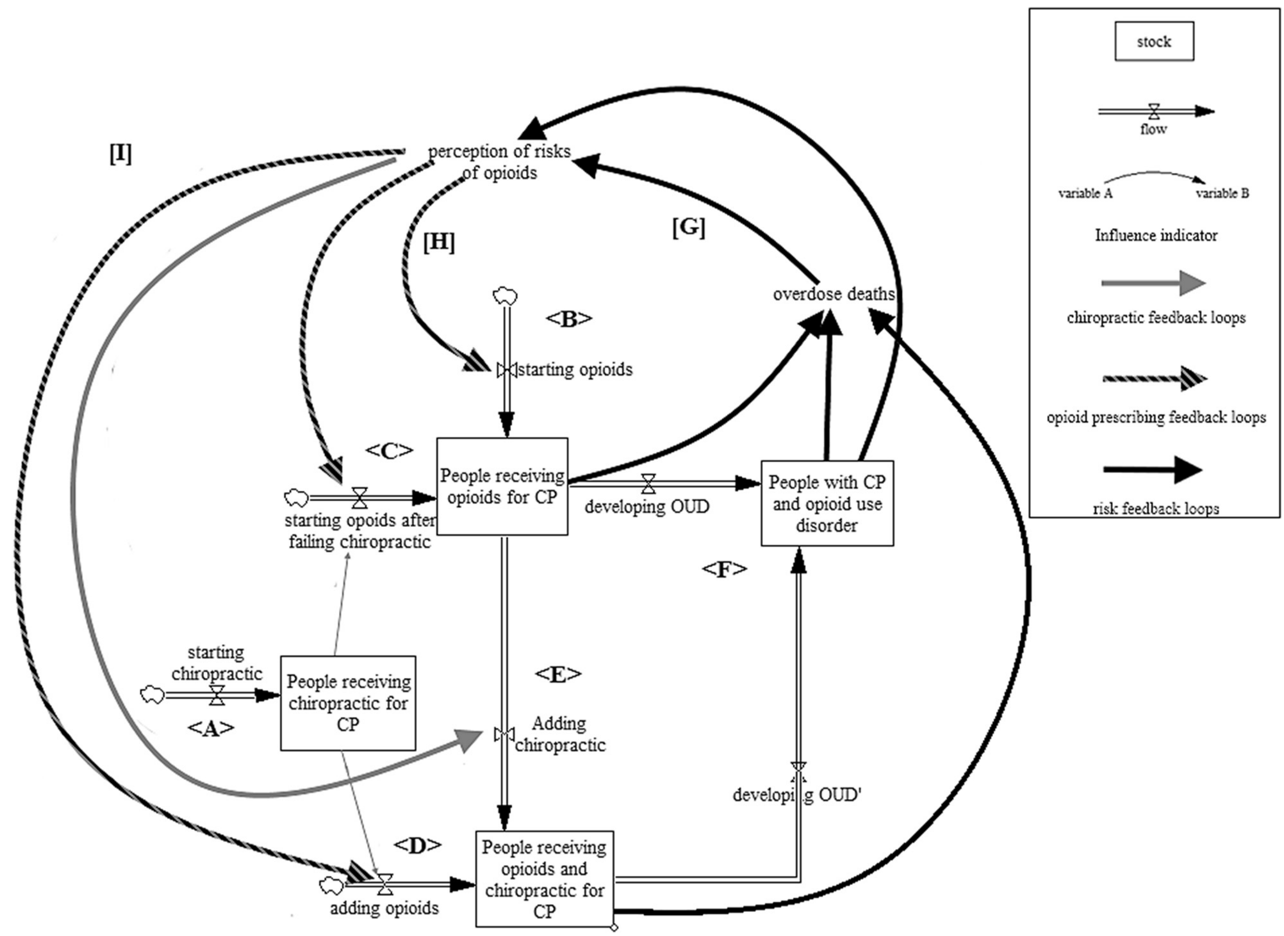

Fig 1. *Model of chronic nonmalignant pain patients, opioid use, and chiropractic care.* CP*, chronic pain;* OUD*, opioid use disorder.*

this discrimination was not a significant indicator of change related to opioid-associated deaths; consequently, the short and long-acting portions of the model were unified for this research. The study was granted approval from the Canadian Memorial Chiropractic College Research Ethics Board (protocol number 152011, approval number 1512X02).

Our model is based on the assumption that patients self-select their choice of care (chiropractic or medicine) at the outset. Data for success of chiropractic care for patients' musculoskeletal pain are based in the literature.[26] However, no data are currently available to suggest success rates for patients already dependent on opioids who are then offered chiropractic. For this and other variables necessary to complete the model where no research was available, assumptions were made by the authors based on experience. These variables where assumptions were made illustrate research gaps and are framed as results for consideration of priorities in a research agenda focused on chiropractic and opioid use.

Table 1 provides a list of data and assumptions (based on author experience and consensus, for the purposes of hypothesis generation) used to build the model.

The model allows for the dynamic hypothesis testing of the impact of introducing chiropractic care at 3 distinct points, namely:

1. Divert patients early. In the first point, chiropractic care is included when the chronic pain patient first seeks care, as literature suggests it may significantly mitigate opioid use.[15,33-35]
2. Collaboration. The second point is based on research suggesting chiropractic care is used in conjunction with rather than instead of conventional care.[19,36] This is logical considering the majority of chronic nonmalignant pain is musculoskeletal in origin,[14,37] and such patients are likely to see both chiropractors and physicians.[38]
3. Beating dependence. In the third unique point, chiropractic care is included as a means of treating pain in people who had already developed an OUD to treat pain without using opioids in conjunction with treating OUD. Chiropractic care is included at this point in the opioid medical cycle to assess its impact

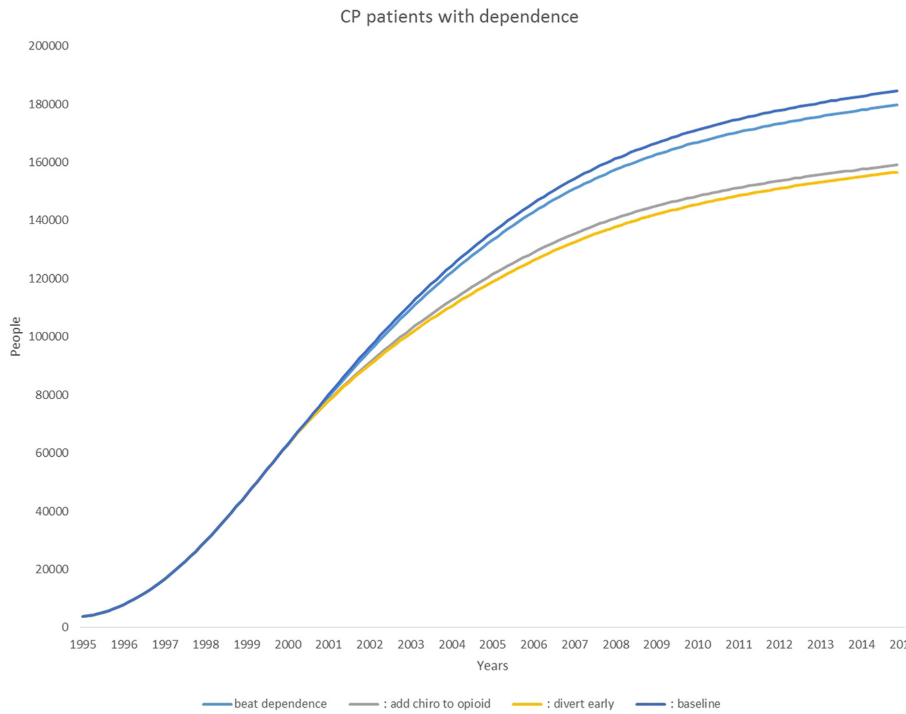

Fig 2. *Policy change and changes in CP patients with dependence on opioids.* CP, *chronic pain.*

on cost-benefit. This final step was included based on recognition that the problem of addiction is difficult to resolve and the costs associated with opioid abuse are substantial.[39] Therefore, although fewer patients might be helped by any form of care (including chiropractic) at this stage, the overall cost to society and to the patient could justify a trial where only small numbers would be anticipated to have a successful outcome.

The primary outcome variables used to test the dynamic hypotheses were number of patients addicted to opioids and number of opioid-related deaths. Implementation of changes in chiropractic care was allowed to occur in 2000, and the results were analyzed for a 15-year period (2015). Primary analysis was a difference of proportions test for each of the outcomes relative to the overall Canadian population.

The model boundary excluded nonmedical opioid use. It also did not consider the impact of educational interventions for caregivers regarding the evolving understanding of opioid risks nor education related to the opportunity for alternative nonpharmacologic pain management.

Statistical analysis evaluating the results of proposed policy changes used Stata SE 8.2 statistical package (StataCorp LP, College Station, Texas). Analysis consisted of one-proportion z tests, using a *P* value cutoff of .01 to account for multiple testing. As population-based data were used, the assumptions that $np_0 > 10$ and $n(1-p_0) > 10$ and the sample is simple random were met.

Results

Figure 1 shows a simplified representation of the stocks and flows in the SD model and 2 primary feedback loops that drive model dynamics. The full SD model is included in Appendix A. The simplified diagram contains many feedback loops. In this description, we highlight and group the loops into 2 principal types of feedback loops: the effect of opioid overdose deaths and OUD (black) on opioid prescribing (striped), and the effect of opioid overdose deaths and OUD (black) on the addition of chiropractic care to opioid therapy for collaborative pain management (gray). Perceived risk of opioid use drives opioid prescribing down and drives the addition of chiropractic comanagement up. Relationships that are important to model dynamics but that do not play a role in the feedback loops are included in light gray.

The basic model dynamics are illustrated in Figure 1. The population flows are labeled in the figure with letters in “< >” brackets, and arrows indicating causal influence between variables are labeled with “[ ]” brackets. Population stocks are identified by name and labeled with quotation marks in the narrative description. These labels are referenced in the narrative description to guide readers

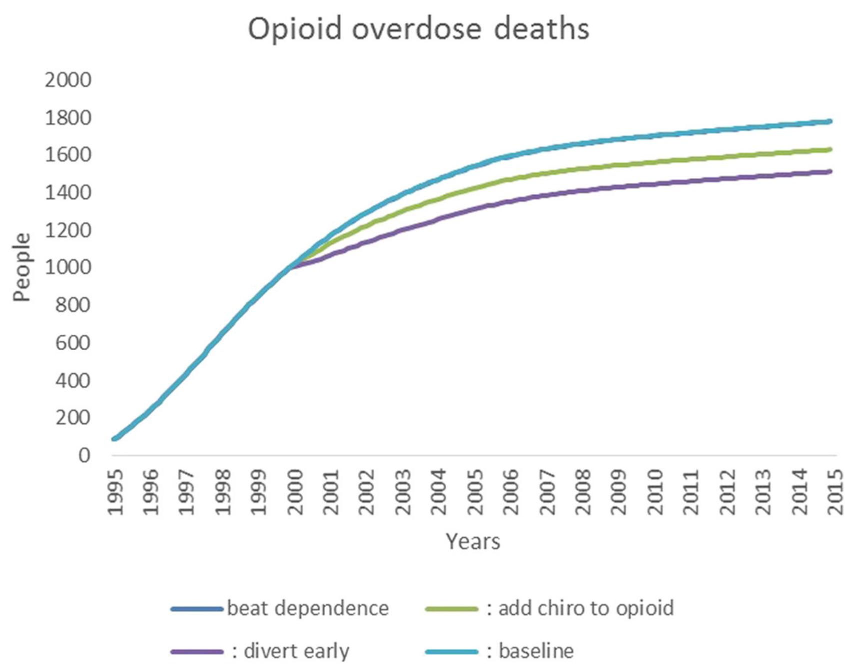

Fig 3. *Policy change and changes in opioid-related deaths.*

through the model dynamics. The rate of patients receiving chiropractic care (<A> starting chiropractic) was predicated on the number of new patients from the Canadian population each year who enter the chronic pain cycle and who self-select into chiropractic for pain management. People starting chiropractic care enter the stock of "people receiving chiropractic care for CP." People may continue and complete their chiropractic care or find that chiropractic care does not provide adequate pain management. In such cases, people may discontinue chiropractic and switch to pain management with opioids (<C> starting opioids) or choose to manage pain with opioids and chiropractic care (<D> adding opioids). Other people may choose to start using opioids for chronic pain (<B> starting opioids) based on the base rate at which patients typically receive opioids for chronic pain and the perception of the risks of opioids. [H] Perception of the risks of opioid use modifies all rates of opioid prescribing (<B>, <C>, and <D>). People starting opioid therapy only (<B> and <C>) enter the stock of "people receiving opioids for CP." A fraction of people in this population may wish to add chiropractic to improve pain management (<E> adding chiropractic). Perception of risks of opioid use modifies the rate of adding chiropractic for pain management, driving it up when risk is high [I]. People who use both chiropractic care and opioids for pain management are in the population of "people receiving opioids and chiropractic for CP."

People taking opioids for chronic pain are at risk for developing an OUD. A fraction of "people receiving opioids for CP" and "people receiving opioids and chiropractic for CP" transition to the stock of "people with CP and opioid use disorder" by <F> developing OUD.

People using opioids are at risk for opioid overdose deaths and may die from opioid overdose. As the number of people receiving opioids for pain increases, the number of people who die of opioid overdose increases, as does the number of people with opioid use disorder. [G] These increases drive up the perception of risks of opioids by medical professionals who may increase recommendations for chiropractic as a first option for people newly experiencing chronic pain [I], increase recommendations to add chiropractic to opioid therapy for better pain management as an alternative to dose escalation [I], or decrease the rate at which providers start opioid therapy [H] (Fig 2).

To keep the diagram as simple as possible, flows representing the usual course of care (eg, completing chiropractic care) and mortality and parameters representing base rates for flows (eg. base opioid prescription rate) were omitted from Figure 1. The full model in Appendix A includes all flows and parameters.

Modeled data indicated 1779 opioid-related deaths projected for 2015 for the baseline run and 184 600 opioid-dependent individuals for that same year. The specifics associated with dynamic hypothesis testing were as follows:

1. Divert patients early: To test this, the number of people receiving chiropractic per year for chronic nonmalignant pain was doubled from 0.125 to

0.25. These individuals were then removed from the opioid inflow.

2. Collaboration: This was defined by adding chiropractic care for those patients already in medical care and taking opioids. The number of people per year entering collaborative care was doubled to test this hypothesis. To do so, the base rate for adding chiropractic to opioid therapy was doubled from 0.125 to 0.25.
3. Beating dependence: This was defined by adding a flow out of the "people with CP and opioid use disorder" stock into the "people receiving chiropractic for CP," set to 1% of that patient population per year. In the policy, we assume that 20% of patients will be offered chiropractic for pain management as part of a treatment program and that it will be effective in helping people into recovery in 5% of those cases. (Fig 3)

Over the 15-year interval of assumed policy implementation, statistically significant results were found in almost all instances where chiropractic care was added to the model. For policy change related to chronic pain patients, diverting patients early yielded a significant decrease in dependence (z = 65.25, $P < .0001$, standard error [SE]: 0.000011) (Fig 2). Collaborative care also resulted in a significant decrease in dependence with z = 59.39, $P < .0001$, SE: 0.000011. Beating dependence had a notably smaller z value at 11.71. However, the *P* value was still less than .0001 (SE: 0.000012).

When considering deaths related to opioid overuse, diverting patients early resulted in a significant drop in the number of deaths (z = 6.38, $P < .0001$, SE: 0.0000011) (Fig 3), and collaboration also resulted in decreased deaths (z = 3.57, $P = .0004$, SE: 0.0000011). There was no statistically significant change in the number of deaths when the beating dependence policy (ie, patients recovering from dependence) was implemented (z = 0.03, $P = .9797$, SE: 0.0000012).

Discussion

Large pragmatic, population-based studies of policy change to manage challenging and complex clinical situations are extremely costly and time-consuming. As a result, such studies should be predicated on the best use of available knowledge. Systematic and scoping reviews have been used to logically move health care research agendas forward by determining gaps in knowledge and fostering the next appropriate questions.[5,6,40] However, cross-sectional information isolated from the complexity of the system within which it resides excludes the feedback loops and unintended consequences of what are presumed to be simple changes in a wider system.[41] System dynamics can be used to merge current data with the impact of assumptions and thus provide a greater understanding of how researchers can reasonably move forward with necessary methods and resources.

The alarming utilization of opioids has been followed by a call for well-designed clinical trials to determine the role that complementary and alternative therapies such as chiropractic care can play in mitigating the challenges of current medical treatment for chronic nonmalignant pain.[32] Such clinical trials are, however, extremely costly and difficult to conduct. System dynamics has been previously used to model assumptions and lengthy timelines associated with large and complex problems in health care.[12] Modeling to inform policy decision-making has also provided guidance in response to clinical challenges in other arenas.[42]

The US guidelines-based policy changes in the late 1990s liberalizing the use of opioids for chronic nonmalignant pain resulted in the direct or indirect death of over 100 000 persons.[43] Changes in opioid prescription patterns similarly occurred in Canada. Oxycodone was approved by Health Canada in 1996. From 1991 to 2007, opioid-related deaths doubled in the province of Ontario.[44] In 2009, Franklin and colleagues[15] studied opioid use for chronic low-back pain in injured workers within Washington state. Among the results predicting long-term use of opioids was the determination of a "dramatically lower odds associated with seeing a chiropractor initially" (p. 749). This is consistent with a finding by Turner and colleagues from 1 year earlier[17] suggesting a reduced risk of long-term disability among workers with back pain, associated with early chiropractic intervention. Caudill-Slosberg, Schwartz, and Woloshin[45] observed an expanded promotion of the use of opioids for chronic nonmalignant pain, including back pain, between 1980 and 2000. For example, the use of morphine, typically related to cancer, experienced a 6-fold increase for use in acute musculoskeletal pain and a 4-fold increase for chronic musculoskeletal pain.

In our model, we adapted work published between 2011 and 2015 by Wakeland and his team[20-22] looking at pharmaceutical and nonmedical opioid use and OUD. Our model also considers the need for studies associated with chiropractic care for chronic nonmalignant pain, and the most likely levers for change in both dependence and opioid-associated deaths. Each of the 3 tested dynamic hypotheses resulted in statistically meaningful change, with the exception of the number of deaths when the assumed beating dependence policy was implemented. As anticipated, the results were most profound when chiropractic care was initiated early. This was consistent with the work of Franklin and colleagues.[15] Preventing dependence appeared to have a much higher impact than overcoming an already acquired dependence. Testing beginning chiropractic care before the onset of addiction also resulted in a significant decrease in death. Specifically, the model estimated that after 15 years, there would be a decrease in deaths from a baseline of 1779 to 1511 (15% reduction) if chiropractic care was used as a substitute for opioids, and from 1779 to 1629 (8% reduction) when chiropractic care was used collaboratively. Preventing opioid-related deaths was also, as expected, much more challenging with care beginning after addiction, and the results indicated no change in the number of deaths when this policy was implemented.

Regarding change in addiction, the cost of substance abuse associated with tobacco, alcohol, and illicit drugs in Canada in 2002 was estimated at approximately $40 billion,[46] implying a cost of approximately $1200 for each Canadian. Assuming the cost for health care and to society is the same for those abusing prescription medication, and if the model accurately predicted a policy impact decreasing the number of addicted individuals by 28 000 fewer people, then the estimated savings would be $33.6 million.

The results of our model project that early intervention with chiropractic care would yield the most promising results. Most effective is prevention of opioid use when possible, followed by collaborative care.

System dynamics modeling can be useful in understanding the current state of the art for the complex environment associated with alternative care for opioid use and abuse. Randomized clinical trials (RCTs) are the study design of choice to provide the high-value data necessary for clinicians and policymakers. An RCT to look at the real-world impact of providing chiropractic care to patients before consideration of medical opioid use would normally be recommended following the observation of the paucity of data currently available in this area. However, given the many assumptions and challenges in conducting such a trial, our modeling suggests that a pragmatic clinical trial involving both patients who would typically be expected to receive medical care but would have a trial of chiropractic care first, and those currently taking opioids who could be comanaged by chiropractors, may be the most practical design. The SD model also provided a valuable understanding of the challenges to undertaking either an RCT or a pragmatic trial, including an appreciation for the large number of participants (approximately 60 000 to 100 000 participants) required to realize the anticipated gains. This exercise has unearthed substantial gaps in the literature, pointing to the necessity for studies designed to address current assumptions using hard data before embarking on such a study. It may be more feasible to use clinical trials to evaluate the remaining assumptions in the model and guide necessary study of the area before consideration of such a large undertaking.

Limitations

This model assumes that patients self-select to chiropractic care. Evidence has been provided by Field and Newell[26] from the United Kingdom that regardless of entry method (self-selection versus referral), patients report significant improvement irrespective of risk category. Others suggest that patients self-selecting to chiropractors have unmeasured characteristics that could affect prognosis.[15,17,47,48] Because this issue remains unresolved, the impact of self-selection versus referral on the model remains unclear.

The first dynamic hypothesis for this model tests the impact of diverting patients directly to chiropractic care before medical intervention. Literature suggesting the benefit of such a strategy came from Franklin et al.[15] Although these researchers found a positive effect related to seeing a chiropractor first, it is understood that their work looked at the progression of patients from acute to chronic pain. No literature was found regarding the impact of chronic patients seeking chiropractic care first. Although a conservative success rate was used in the creation of the model to mitigate this problem, more accuracy for this dynamic hypothesis might be inferred with better data.

Creating a viable SD model, however, illuminated the many assumptions that exist in this complex system for which no real data are currently available. As indicated in Table 1, of the 20 parameters used in the model, over one-third (7 of 20) had to be assumed. Still others could not be directly taken from research study data, but rather were imputed or derived. Low-dose opioid deaths, for example, was an assumed rate not available in nationwide gathered statistics. The success and failure rate for chiropractic care was taken from older work involving a wide spectrum of cases, including radicular pain.[28] This provided a relatively conservative estimate; however, it is understood that success rates vary considerably. System dynamics modeling allows for these rates to be modified and tested as newer and better data are available.

Much of the data that were available for parameter use came from information from US studies. Canadian data for much of this work are unavailable, regardless of the increasing alarm associated with opioid use and abuse for pain relief. Thus, data to facilitate the creation of appropriate research on alternatives for patient care are severely lacking.

Conclusion

Systematic reviews and scoping reviews have both been used to identify gaps in health care research and facilitate the identification of the next logical research question in a complex field of study. These reviews, however, are not typically contextualized in the health care system within which they reside. As a result, feedback loops that affect research feasibility and design are missed. Our study developed an SD model of the impact of chiropractic in the treatment of patients with musculoskeletal pain who are either taking opiods or are candidates for opioid use. The model provides clear evidence of the challenges associated with the creation of such an investigation and points to areas of need for future study. System dynamics modeling may be an adjunct tool in identifying useful and feasible research questions and design challenges for complex health care problems.

Funding Sources and Conflicts of Interest

Funding was received from the Ontario Chiropractic Association for this project. No conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): M.M., C.C., M.D.F., S.M.

Design (planned the methods to generate the results): M.M., A.N., M.D.F., W.W.

Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): M.M., A.N., S.M.

Data collection/processing (responsible for experiments, patient management, organization, or reporting data): M.M., A.N., M.D.F.

Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): M.M., A.N., W.W.

Literature search (performed the literature search): M.M., C.C., M.D.F.

Writing (responsible for writing a substantive part of the manuscript): M.M., A.N.

Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): M.M., A.N., C.C., M.D.F., W.W., S.M.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jmpt.2018.11.007.

Practical Applications

- System dynamics modeling allows for graphical representation of the impact of treatment over time, clearly elaborating assumptions where no data currently exist.
- This study provides an example of SD modeling of the impact of chiropractic care for chronic musculoskeletal pain providing both outcomes resulting from assumptions that currently exist and an understanding of the practical needs of future studies that should be undertaken.

References

1. Kahwati L, Jacobs S, Kane H, Lewis M, Viswanathan M, Golin CE. Using qualitative comparative analysis in a systematic review of a complex intervention. *Syst Rev.* 2016;5:82.
2. Russell R, Chung M, Balk EM, et al. AHRQ technical reviews. In: *Issues and Challenges in Conducting Systematic Reviews to Support Development of Nutrient Reference Values: Workshop Summary: Nutrition Research Series, Vol. 2*. Rockville, MD: Agency for Healthcare Research and Quality; 2009.
3. Booth A. Searching for qualitative research for inclusion in systematic reviews: a structured methodological review. *Syst Rev.* 2016;5:74.
4. Herrmann D, Sinnett P, Holmes J, Khan S, Koller C, Vassar M. Statistical controversies in clinical research: publication bias evaluations are not routinely conducted in clinical oncology systematic reviews. *Ann Oncol.* 2017;28(5):931-937.
5. Anderson S, Allen P, Peckham S, Goodwin N. Asking the right questions: scoping studies in the commissioning of research on the organisation and delivery of health services. *Health Res Policy Syst.* 2008;6:7.
6. Tricco AC, Lillie E, Zarin W, et al. A scoping review on the conduct and reporting of scoping reviews. *BMC Med Res Methodol.* 2016;16:15.
7. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Social Res Methodol.* 2005;8(1):19-32.
8. Davis K, Drey N, Gould D. What are scoping studies? A review of the nursing literature. *Int J Nurs Stud.* 2009;46(10):1386-1400.
9. Ehrich K, Freeman GK, Richards SC, Robinson IC, Shepperd S. How to do a scoping exercise: continuity of care. *Res Policy Plann.* 2002;20(1):25-29.
10. Forrester JW. *Industrial Dynamics*. Cambridge, MA: MIT Press; 1960.
11. Business Dynamics Sterman JD. *Systems Thinking and Modeling for a Complex World*. McGraw Hill; 2000.
12. Homer JB, Hirsch GB. System dynamics modeling for public health: background and opportunities. *Am J Public Health.* 2006;96(3):452-458.
13. Stannard C, Moore A. Traditional opioids for chronic non-cancer pain: untidy, unsatisfactory, and probably unsuitable. Evidently Cochrane. Vol 20182016.
14. National Academies of Sciences. *E, Medicine. Pain Management and the Opioid Epidemic: Balancing Societal and Individual Benefits and Risks of Prescription Opioid Use*. National Academies Press; 2017.
15. Franklin GM, Rahman EA, Turner JA, Daniell WE, Fulton-Kehoe D. Opioid use for chronic low back pain: a prospective, population-based study among injured workers in Washington state, 2002-2005. *Clin J Pain.* 2009;25(9):743-751.
16. Haas M, Groupp E, Kraemer DF. Dose-response for chiropractic care of chronic low back pain. *Spine J.* 2004;4(5):574-583.
17. Turner JA, Franklin G, Fulton-Kehoe D, et al. ISSLS prize winner: early predictors of chronic work disability: a prospective, population-based study of workers with back injuries. *Spine.* 2008;33(25):2809-2818.
18. Weeks WB, Goertz CM. Cross-sectional analysis of per capita supply of doctors of chiropractic and opioid use in younger Medicare beneficiaries. *J Manipulative Physiol Ther.* 2016;39(4):263-266.
19. Goertz CM, Long CR, Vining RD, Pohlman KA, Walter J, Coulter I. Effect of usual medical care plus chiropractic care vs usual medical care alone on pain and disability among US service members with low back pain: a comparative effectiveness clinical trial. *JAMA Network Open.* 2018;1(1)e180105.

20. Wakeland W, Nielsen A, Geissert P. Dynamic model of nonmedical opioid use trajectories and potential policy interventions. *Am J Drug Alcohol Abuse.* 2015;41(6):508-518.
21. Wakeland W, Nielsen A, Schmidt TD, et al. Modeling the impact of simulated educational interventions on the use and abuse of pharmaceutical opioids in the United States: a report on initial efforts. *Health Educ Behav.* 2013;40(1 suppl): 74s-86s.
22. Wakeland W, Schmidt T, Gilson AM, Haddox JD, Webster LR. System dynamics modeling as a potentially useful tool in analyzing mitigation strategies to reduce overdose deaths associated with pharmaceutical opioid treatment of chronic pain. *Pain Med.* 2011;12(suppl 2):S49-S58.
23. Gomes T, Mamdani MM, Dhalla IA, Paterson JM, Juurlink DN. Opioid dose and drug-related mortality in patients with nonmalignant pain. *Archives Internal Med.* 2011;171(7):686-691.
24. Statistics Canada. Population and dwelling count highlight tables, 2011 Census. Available at: http://www12.statcan.ca/census-recensement/2011/dp-pd/hlt-fst/pd-pl/Table-Tableau.cfm?LANG=Eng&T=101&S=50&O=A. Accessed March 21, 2016.
25. Statistics Canada. Table 1: Deaths by sex and geography. Available at: http://www.statcan.gc.ca/pub/84f0211x/2009000/t001-eng.htm. Accessed March 21, 2016.
26. Field JR, Newell D. Clinical outcomes in a large cohort of musculoskeletal patients undergoing chiropractic care in the United Kingdom: a comparison of self- and National Health Service–referred routes. *J Manipulative Physiol Ther.* 2016;39(1):54-62.
27. Peter D. Hart Research Associates. Americans talk about pain: a survey among adults nationwide conducted for Research! America. Available at: https://www.researchamerica.org/sites/default/files/uploads/poll2003pain.pdf.
28. Cassidy J, Kirkaldy-Willis W, McGregor M. Spinal manipulation for the treatment of chronic low back and leg pain: an observational study. In: Bueger A, Greenman P, eds. *Empirical Approaches to the Validation of Spinal Manipulation*. Springfield, IL: CC Thomas; 1985. p. 119-148.
29. Chou R, Turner JA, Devine EB, et al. The effectiveness and risks of long-term opioid therapy for chronic pain: a systematic review for a National Institutes of Health Pathways to Prevention Workshop. *Ann Internal Med.* 2015;162(4):276-286.
30. World Health Organization. International Statistical Classification of Diseases and Related Health Problems. Vol 1: World Health Organization; 2004.
31. Regier L. Opioid tapering - when reducing or discontinuing an opioid in chronic non-cancer pain. Available at: http://www.rxfiles.ca.
32. Fleming S, Rabago DP, Mundt MP, Fleming MF. CAM therapies among primary care patients using opioid therapy for chronic pain. *BMC Complement Altern Med.* 2007;7:15.
33. Whedon JM, Toler AW, Goehl JM, Kazal LA. Association between utilization of chiropractic services for treatment of low back pain and risk of adverse drug events. *J Manipulative Physiol Ther.* 2018;41(5):383-388.
34. Carnide NG. *Early Opioid Prescriptions for Work-Related Musculoskeletal Disorders of the Low Back: Understanding Dispensing Patterns, Their Determinants, and Their Impact on Work Disability*. Toronto: Canada; University of Toronto; 2017.
35. Rhee Y, Taitel MS, Walker DR, Lau DT. Narcotic drug use among patients with lower back pain in employer health plans: a retrospective analysis of risk factors and health care services. *Clin Ther.* 2007;29(11):2603-2612.
36. Foltz V, St Pierre Y, Rozenberg S, et al. Use of complementary and alternative therapies by patients with self-reported chronic back pain: a nationwide survey in Canada. *Joint Bone Spine.* 2005;72(6):571-577.
37. Schopflocher D, Taenzer P, Jovey R. The prevalence of chronic pain in Canada. *Pain Res Manage.* 2011;16(6):445-450.
38. Wolsko PM, Eisenberg DM, Davis RB, Kessler R, Phillips RS. Patterns and perceptions of care for treatment of back and neck pain: results of a national survey. *Spine.* 2003;28(3):292-297 discussion 298.
39. Birnbaum HG, White AG, Schiller M, Waldman T, Cleveland JM, Roland CL. Societal costs of prescription opioid abuse, dependence, and misuse in the United States. *Pain Med.* 2011;12(4):657-667.
40. Viswanathan M, Nerz P, Dalberth B, et al. Assessing the impact of systematic reviews on future research: two case studies. *J Comp Effectiveness Res.* 2012;1(4):329-346.
41. Sterman JD. Learning in and about complex systems. *Syst Dyn Rev.* 1994;10(2-3):291-330.
42. Ghaffarzadegan N, Epstein AJ, Martin EG. Practice variation, bias, and experiential learning in cesarean delivery: a data-based system dynamics approach. *Health Serv Res.* 2013;48(2 Pt 2):713-734.
43. Franklin GM. Opioids for chronic noncancer pain: a position paper of the American Academy of Neurology. *Neurology.* 2014;83(14):1277-1284.
44. Dhalla IA, Mamdani MM, Sivilotti ML, Kopp A, Qureshi O, Juurlink DN. Prescribing of opioid analgesics and related mortality before and after the introduction of long-acting oxycodone. *CMAJ.* 2009;181(12):891-896.
45. Caudill-Slosberg MA, Schwartz LM, Woloshin S. Office visits and analgesic prescriptions for musculoskeletal pain in US: 1980 vs. 2000. *Pain.* 2004;109(3):514-519.
46. Rehm J, Baliunas D, Brochu S, et al. *The Costs of Substance Abuse in Canada 2002 Highlights*. Ottawa, Ontario, Canada: Canadian Centre on Substance Abuse; 2006. Available at: http://www.ccsa.ca/Resource%20Library/ccsa-011332-2006.pdf. Accessed September 12, 2015.
47. Sharma R, Haas M, Stano M. Patient attitudes, insurance, and other determinants of self-referral to medical and chiropractic physicians. *Am J Public Health.* 2003;93(12):2111-2117.
48. Nyiendo J, Haas M, Goldberg B, Sexton G. Pain, disability, and satisfation outcomes and predictors of outcomes: a practice-based study of chronic low back pain patients attending primary care and chiropractic physicians. *J Manipulative Physiol Ther.* 2001;24(7):433-439.