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System Dynamics Modeling of Caries Severity States in Long-term Care

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Abstract

Dental caries among long-term care (LTC) residents is a persistent and complex problem driven by social and structural factors. Systems Thinking may be useful in considering novel approaches to reducing disease. This study aimed to develop a system dynamics model to simulate the progression of dentate older adults in LTC through caries severity states and estimate the effects of three intervention scenarios on the progression of caries: preventive topical fluoride (TF), arrest of caries with silver diamine fluoride (SDF), and a combination of TF and SDF. Dentate older adults in LTC were categorized into four caries severity states by their number of untreated carious lesions. The model assumed that changes in severity states were consistent with incidence rates reported in the literature and available billing data for dental care, and that individuals move in and out of the system by entering and exiting the facility or experiencing edentulism. For all scenarios, the proportion of dentate older adults in LTC with one or more untreated lesions stays stable, the distribution of disease shifts from a high severity state and the system approaches equilibrium after four years. The TF intervention predicts minimal impacts on decreasing the proportion of dentate older adults with one or more untreated lesions (2.5% decrease), while the SDF intervention and the combination interventions were most disruptive. There was a 29.6% and 33.6% decrease respectively. Given the specific population dynamics in LTC, these findings suggest that long term (greater than four years) interventions should be designed to address both the management of existing lesions as well as their incidence. This system dynamics model allows researchers to render institution-specific data points from LTCs to estimate the effects of proposed interventions at the respective site.

Introduction

In the United States, dental caries remains the most prevalent chronic disease among older adults with 96% of adults aged 65 or older having one or more carious lesions (Dye et al. 2015). Further, the severity of oral diseases is greater among older adults in long-term care (LTC) (Turton et al. 2024). The extent of oral diseases among older adults in LTC is understudied and current data likely underestimate the severity. Efforts to address this problem have been limited to intervening with a single treatment modality, working with one type of clinician, using outcome measures of limited utility such as plaque scores rather than disease severity, and observing outcomes over short periods. Previous studies have discussed the influence of social determinants on oral health behaviors but existing work has not considered those social and structural drivers in the context interventions to reduce oral diseases in LTC (Tellez et al. 2014; de Abreu et al. 2021). Compared to community-dwelling older adults, persons in LTC have lower physical function and less agency, factors that decrease the ability to engage in oral health-promoting behaviors (Toth et al. 2020). The severe burden of oral disease in an aging population underscores the need to embrace emerging approaches in geriatric dentistry that prioritize preserving oral function, such as minimally intervention dentistry (MID), and consider the systems-level influences on oral health (León and Giacaman 2022). Such an approach would consider the complexity associated with a range of factors as they impact oral health and how said factors interact with and impact one another.

The application of systems thinking to population health has grown in popularity; however, it is still relatively new to the field of oral health. Systems thinking acknowledges the presence of multiple components within a system that depend on and relate to one another to influence the properties of a system. System dynamics, a systems thinking tool, is a mathematical modeling methodology that simulates the feedback and interactions between elements of complex systems (Heaton and Baker, 2023). Previous studies applying systems thinking to oral health have examined early childhood caries interventions to inform policy and mapped the system influencing oral health among older adults, but none have examined older adults in LTC (Metcalf et al. 2011; Hirsch et al. 2012; Metcalf et al. 2013; Edelstein et al. 2015; Northridge and Metcalf 2016; Heaton et al. 2020). Given the unique institutional-level factors influencing oral disease in this setting, it would be appropriate to examine the system dynamics of oral health among older adults in LTC.

It is useful to consider dental caries outcomes at a population level, in the context of the unique population dynamics, the distribution of disease across clinically relevant severity states, and using interventions that could be performed as part of routine care delivered through systems, processes, and staff who are already present within the institution. This contrasts with existing intervention studies that rely on clinicians who are not part of the LTC facility and use individual-level disease indicators that are often dichotomous (e.g., presence or absence of untreated lesions) or continuous (e.g., DMFT or mean plaque scores). The reframing towards population-level indicators aligns with the concept of dental caries as a disease driven by social and structural factors and not purely one of individual choice.

Novel indicators such as population flux and the proportion of individuals in clinically relevant caries severity states might be more likely to inform assessments as to whether an institution is functioning in a way that supports oral health. This study aimed first to develop a system dynamics model to estimate the movement of older adults among caries severity states while in LTC facilities in the United States. Second, it aimed to estimate the range of effects that three intervention scenarios might have on the system dynamics.

Methods

A system dynamics model for understanding caries progression among dentate older adults living in LTC facilities was developed using Vensim PLE (Version 10.1.0) ([VS] 2023). The working model was published in Open Science Framework (interested parties can access) (Turton and Griffith 2024). The Boston University Medical Campus and Boston Medical Center Institutional Review Board (IRB) approved this study (H-42102).

Model Structure

Stocks and flows, two system dynamics tools, are the model variables. Stocks are measures that can change value over time and flows are rates that influence stock values. The parameter estimates for these variables were estimated from a scoping review of oral health in LTC and billing data from one LTC facility in Boston, Massachusetts, where 234 dentate residents were served over one year (Turton et al. 2024). The estimates were used to model the current system of caries

progression, referred to as the reference population. Patient narratives are presented in the supplementary materials to illustrate the movement of individuals among severity states.

Peer-reviewed literature estimated relevant measures among older adults in LTC, including the prevalence of untreated caries, distribution of caries severity, incidence of caries, and edentulism. Table 1 shows descriptions of the model's parameter estimates, their data sources, and how they were used in the model. Electronic medical records from one LTC facility were used to inform dental restoration rates by a range of effects (restoring 1-3, 4-6, or greater than 6 lesions). Peer-reviewed literature was used to estimate the effects of topical fluoride and silver diamine fluoride (SDF) interventions on lesion incidence and caries arrest.

Caries experience is characterized as an ordinal variable with four stocks based on the number of individual untreated carious lesions (assumed to be active untreated lesions). The four stocks represent caries severity states defined as the proportion of dentate older adults living in LTC that have (1) no untreated carious lesions, (2) one to three untreated carious lesions (low severity), (3) four to six untreated carious lesions (medium severity), or (4) more than six untreated carious lesions (high severity). At any point, the sum of all stocks is 100. At time $t=0$, the value of the stocks is the estimated baseline distribution of disease detailed in Table 1. The model is simulated with time intervals of one year to predict the distribution of caries severity states over five years.

At the initialization of the model, all dentate older adults living in LTC are characterized by their caries severity state. The population can progress to higher severity states using the average incidence of lesions and can revert to lower severity states by the average lesion restoration rates. The model provides a depiction of the current system of dental disease severity in the presence of dental care utilization as experienced by the reference population and estimates the effects of evidence-based interventions on the system via three scenarios:

1. A topical fluoride intervention with floor and ceiling effects (20-40% reduction in incidence (Bansal et al. 2015))
2. A SDF intervention for the arrest of caries (70% arrest of active caries lesions (Seifo et al. 2019))

3. A combination of topical fluoride and SDF interventions

Assumptions

The model simulates caries progression among a dynamic population of dentate adults that is in flux. We derived a population turnover rate of 30% based on the facility's estimated mortality rate from a previous study at the LTC facility of interest (Rawal 2018). We estimate 30% of dentate adults across all severity states leave the facility annually and flow out of the model at a rate of 30% per year; this proportion is replaced with an inflow of dentate adults to the facility. The population entering is distributed based on the initial severity state distributions.

This model excludes edentulous older adults living in LTC. The other pathway flowing out of the model is by dentate adults becoming edentulous. This outflow rate is simulated at 1% per year (Nevalainen et al. 2004).

A deterministic sensitivity analysis was performed to test the assumptions of the parameter estimates and results are presented in the supplementary materials.

Results

Figure 1 shows the conceptual systems dynamics model that simulates the current system of caries progression and dental care utilization for the reference population. This model also simulates the impact of interventions on caries progression.

Figure 2 projects the proportion of dentate older adults in LTC with one or more untreated carious lesions over five years. It appears to take around four years for the benefits of the interventions to plateau. All scenarios begin with the 70% proportion estimate of older adults with at least one untreated carious lesion for the reference population. In the absence of intervention, the reference population is projected to increase its proportion of dentate older adults with one or more untreated carious lesions from 70% to 75%. The topical fluoride intervention has a minimal projected impact on this proportion (<5% decrease), while the SDF intervention has a substantial projected impact on this proportion (29.6% decrease). The combined topical fluoride and SDF intervention projects

a slightly further decrease in the overall proportion with one or more untreated carious lesions compared to the SDF intervention alone (33.6%).

Table 2 shows the distribution of caries severity states among the reference population and the three intervention scenarios over five years. In the reference population, the proportion of dentate older adults in the high-severity state increased from 17.5% to 34.4%, while the medium severity state decreased from 35% to 23.8%.

Applying the topical fluoride intervention (Scenario 1) to the model has a small projected impact on changes in caries severity states, with only a 1.2% to 2.5% comparative increase in the proportion of dentate older adults with no untreated carious lesions after five years. The greatest effects of the topical fluoride intervention are seen in changes in the high severity state after five years; the high severity state is between 3.1% to 6.4% lower compared to the reference population (Reference population=34.4%; Scenario 1 model population=31.3% to 28%).

The SDF intervention (Scenario 2) projects a 29.6% greater proportion of dentate older adults with no untreated lesions compared to the reference cohort after five years. Unlike in the reference population and the model with the topical fluoride intervention, the proportion in the high severity state does not increase at any point over five years.

Adding the topical fluoride's 20% to 40% window of effect to the SDF intervention only minimally increases the overall proportion with no untreated carious lesions after five years. The combined SDF and topical fluoride intervention (Scenario 3) exhibits synergy. As seen in Table 2, the overall proportion with no untreated carious lesions after five years (57.1% to 59.2%) is greater in this scenario compared to the two interventions alone (Topical fluoride=26.8% to 28.1%; SDF=55.2%). After five years, the proportion of dentate older adults in the low, medium, and high severity states in Scenario 3 is lower compared to the respective low, medium, and high severity states in either intervention alone.

All three scenarios approach equilibrium in years four and five, with the greatest changes occurring between years one and three.

Figure 3 shows the projected distribution of caries severity states at five years among the reference population and in the three scenarios. While the topical fluoride minimally changes the

distribution of severity states, the SDF intervention is most disruptive in changing the distribution of caries severity states and shifting the burden of caries away from the highest severity state.

Discussion

This investigation used a novel approach to system dynamics modeling to understand dentate LTC residents' movement among different caries disease severity states over five years in the context of three different scenarios. The process highlighted certain system features relevant to the subsequent co-design processes that hope to influence caries disease severity in LTC settings. The model highlights that: (a) it will take several years before the system stabilizes in response to the scenarios for intervention that were tested suggesting the need for early and sustained intervention; (b) topical fluorides do not greatly impact the pattern of distribution of the population among severity states on their own; (c) changing the pattern of disease requires a therapeutic intervention that will predictably stop lesion progression (SDF). These findings further emphasize the need to develop multi-faceted interventions observed over long periods.

One of the advantages of system dynamics models to complement co-design processes is that it helps investigators identify crucial elements of the system that may have been overlooked due to the lack of available data and to better design outcomes that will be sensitive to relevant changes within the system (Decker and Wendel 2023). Previous studies have examined the promising utility of combining systems thinking and design thinking constructs such as co-design for implementing public health interventions within the field of oral health and beyond (Shrier et al. 2020; Brocklehurst et al. 2021; Heaton and Baker 2023; Whelan et al. 2023). This system dynamics model allows investigators to render institution-specific data points from potential partnering institutions to estimate the effects of proposed interventions. Estimates derived from the model can also inform elements of clinical trial study design.

A limitation of using system dynamics models is that they likely oversimplify complex systems, omit relevant elements of the system, and cannot accurately quantify every incorporated element due to a lack of available data. Further limitations in this approach include inconsistencies in billing patterns due to restrictions in which types of services are remunerated under Medicaid, suggesting

the data likely underestimate the true restoration rates. The effect of this underestimation was tested in the sensitivity analysis. Descriptive data on service utilization are presented in the supplementary materials. The parameter estimates were not generalizable to all LTC facilities in the US, and the purpose of this model is to develop a tool that can aid in co-design to identify agents, processes, and parameters that are likely to have the largest influence on the system.

Another limitation is that estimates of disease experience in LTC, and progression are based on the imperfect data presented in the literature and likely underestimate the severity of disease as surveys tend to exclude those LTC residents who have the highest level of disability (Turton et al. 2024). Clinically relevant cut-offs are defined according to mean values and interquartile ranges in severity (Turton et al. 2024). This approach does not consider the potentially skewed distribution of disease, relevant patient-reported measures, or differences in how disease states or utilization rates might differ by socio-demographic characteristics. Once more detailed epidemiological data are available, clinically relevant caries severity states will be validated.

Further, many factors may impede the attainment of the presumed one hundred percent acceptance and utilization of the suggested interventions. The success of acquiring and using the resources needed for the interventions depends on the LTC's capacity for coordination, having staff to deliver the intervention, cost, and competing duties of staff members. Acceptance of the interventions is contingent on obtaining consent from residents and their family members or health proxies. Compliance with the intervention can be further complicated among older adults with dementia, as these conditions can impact their cognition and behaviors. While existing reports suggest that MID techniques are well accepted by child and adult populations, the acceptability of MID is yet to be explored among residents in LTC (Banerjee 2013; Torres et al. 2021). The impact of these factors on utilization will be explored during subsequent co-design processes.

The interaction between disease severity, exposure to the three interventions, and length of stay is also modeled on a normal distribution. However, it is reported that the pattern around length of stay is more likely to follow one of two patterns, whereby individuals will either have a very short stay (e.g. end of life care or rehabilitation) or a very long stay (Kelly et al. 2010). This pattern is reflected in Massachusetts' Medicaid nursing homes in 2008; the mean length of stay in these LTC facilities was 2.41 years, 46% of length of stays were one year or less, 33% were between one and three years, and 20% were greater than 4 years ([MEOHHS] 2017). It is unclear how this bimodal

pattern might influence the movement of individuals among disease severity states, and this should be considered in the co-design processes. It is likely that short-stay individuals would both miss out on the long-term benefits of intervention and may have a different caries disease profile than those who experience longer stays. For example, if it were to be that those short-stay individuals had an overall more severe caries disease state or there was a higher proportion of short-stay individuals than long-stay individuals, then this would have caused the model to overestimate the benefits of the tested scenarios.

System dynamics models can only incorporate population-level indicators. The present model demonstrated a way of considering how components within a system might interact with the caries disease process. For this reason, parameters that were easily quantified and most likely to be accessible through an electronic medical records system were prioritized. Further work should be focused on validating parameters for the influence of individual-level indicators such as multimorbidity or the co-occurrence of chronic diseases, as it is highly prevalent among older adults and associated with poor oral health (Mirza et al. 2024). The effect of sociodemographic and oral health behaviors should also be explored.

The three scenarios highlighted those preventive interventions using topical fluorides while producing clinically relevant reductions in disease, would have a negligible effect on the movement of individuals among the severity states defined in the model. Further, the effect of topical fluoride application will take five or more years to reach optimal impact on the disease severity states at a population level. Preventive intervention might affect lesion severity (size and depth of the carious lesion) that was not captured by the conditions of severity state used in these models.

This informs our subsequent co-design processes for potential interventions as it indicates that there would be a need for additional therapies, such as SDF, to intervene in the caries process in a way that would meaningfully reduce the proportion of individuals in the more severe caries severity states (Brocklehurst et al. 2021). This model explored the use of SDF for the following reasons: (a) treatment can be provided without the need for injections, drills, or travel to dental surgery; (b) cost efficiency; (c) and the possibility of non-dental providers being able to provide treatment given the recent move by American College of Pediatricians in allowing physicians to bill for the placement of SDF among children (Johnson et al. 2019; Seifo et al. 2020; [AAPD]

2023). SDF is not the only intervention that could potentially intervene in the caries process in this way, and it would be important to consider the perceptions of residents and their families when considering which options to include.

Conclusion

The present study provided insight into the movement of individuals among caries disease severity states within one LTC facility. The model builds the case for minimally invasive techniques such as SDF alone or in combination with preventive topical fluorides to arrest the progression of carious lesions rather than only preventing new lesions from occurring. Future research will employ co-design processes to examine the costs and feasibility of implementing such a combination of interventions or similar interventions in LTC facilities. Modeling suggests that the intervention should be observed for around four years to capture clinically relevant changes in the system.

References

[AAPD] American Academy of Pediatric Dentistry. 2023. Policy on the Use of Silver Diamine Fluoride for Pediatric Dental Patients. Chicago, Ill.; American Academy of Pediatric Dentistry: American Academy of Pediatric Dentistry The Reference Manual of Pediatric Dentistry. [accessed 2024 Apr 18]. https://www.aapd.org/globalassets/media/policies_guidelines/p_silverdiamine.pdf.

de Abreu MHNG, Cruz AJS, Borges-Oliveira AC, Martins R de C, Mattos F de F. 2021. Perspectives on Social and Environmental Determinants of Oral Health. *Int J Environ Res Public Health*. 18(24):13429. doi:10.3390/ijerph182413429.

Banerjee A. 2013. Minimal intervention dentistry: part 7. Minimally invasive operative caries management: rationale and techniques. *Br Dent J*. 214(3):107–111. doi:10.1038/sj.bdj.2013.106.

Brocklehurst PR, Baker SR, Langley J. 2021. Context and the evidence-based paradigm: The potential for participatory research and systems thinking in oral health. *Community Dentistry and Oral Epidemiology*. 49(1):1–9. doi:10.1111/cdoe.12570.

Decker H, Wendel M. 2023. Applications of Participatory System Dynamics Methods to Public Health: A Systematic Review. *Family & Community Health*. 46:S6. doi:10.1097/FCH.0000000000000369.

Dye B, Thornton-Evans G, Li X, Iafolla T. 2015. Dental caries and tooth loss in adults in the United States, 2011-2012. *NCHS Data Brief*.(197):197.

- Edelstein BL, Hirsch G, Frosh M, Kumar J. 2015. Reducing early childhood caries in a Medicaid population: A systems model analysis. *The Journal of the American Dental Association*. 146(4):224–232. doi:10.1016/j.adaj.2014.12.024.
- Heaton B, Baker SR. 2023. Methods to madness: The utility of complex systems science in a mad, mad world. *Community Dentistry and Oral Epidemiology*. 51(1):79–84. doi:10.1111/cdoe.12824.
- Heaton B, Cherng ST, Sohn W, Garcia RI, Galea S. 2020. Complex Systems Model of Dynamic Mechanisms of Early Childhood Caries Development. *Journal of Dental Research*. 99(5):537. doi:10.1177/0022034520909841.
- Hirsch GB, Edelstein BL, Frosh M, Anselmo T. 2012. A Simulation Model for Designing Effective Interventions in Early Childhood Caries. *Prev Chronic Dis*. 9:E66.
- Johhnson B, Serban N, Griffin PM, Tomar SL. 2019. Projecting the economic impact of silver diamine fluoride on caries treatment expenditures and outcomes in young U.S. children. *J Public Health Dent*. 79(3):215–221. doi:10.1111/jphd.12312.
- Kelly A, Conell-Price J, Covinsky K, Cenzer IS, Chang A, Boscardin WJ, Smith AK. 2010. Lengths of Stay for Older Adults Residing in Nursing Homes at the End of Life. *J Am Geriatr Soc*. 58(9):1701–1706. doi:10.1111/j.1532-5415.2010.03005.x.
- León S, Giacaman RA. 2022. Proposal for a Conceptual Framework for the Development of Geriatric Dentistry. *J Dent Res*. 101(3):247–252. doi:10.1177/00220345211042268.
- [MEOHHS] Massachusetts Executive Office of Health and Human Services. 2017. Long-Term Care in Massachusetts: Facts at a Glance. Massachusetts: Massachusetts Executive Office of Health and Human Services. [accessed 2024 Apr 19]. <https://www.mass.gov/doc/ltc-factsheetpdf/download>.
- Metcalf SS, Northridge ME, Lamster IB. 2011. A Systems Perspective for Dental Health in Older Adults. *Am J Public Health*. 101(10):1820–1823. doi:10.2105/AJPH.2011.300321.
- Metcalf SS, Northridge ME, Widener MJ, Chakraborty B, Marshall SE, Lamster IB. 2013. Modeling Social Dimensions of Oral Health Among Older Adults in Urban Environments. *Health Educ Behav*. 40(1_suppl):63S-73S. doi:10.1177/1090198113493781.
- Mirza A, Watt RG, Heilmann A, Stennett M, Singh A. 2024. Social Disadvantage and Multimorbidity Including Oral Conditions in the United States. *J Dent Res*. 103(5):477–483. doi:10.1177/00220345241228834.
- Nevalainen MJ, Närhi TO, Ainamo A. 2004. A 5-year follow-up study on the prosthetic rehabilitation of the elderly in Helsinki, Finland. *Journal of Oral Rehabilitation*. 31(7):647–652. doi:10.1111/j.1365-2842.2004.01280.x.
- Northridge ME, Metcalf SS. 2016. Enhancing implementation science by applying best principles of systems science. *Health Research Policy and Systems*. 14(1):74. doi:10.1186/s12961-016-0146-8.

Rawal K. 2018. End of life dental service utilization by geriatric patients in a long-term care setting. [accessed 2024 Mar 26]. <https://open.bu.edu/handle/2144/32948>.

Seifo N, Robertson M, MacLean J, Blain K, Grosse S, Milne R, Seeballuck C, Innes N. 2020. The use of silver diamine fluoride (SDF) in dental practice. *Br Dent J*. 228(2):75–81. doi:10.1038/s41415-020-1203-9.

Shrier LA, Burke PJ, Jonestrask C, Katz-Wise SL. 2020. Applying Systems Thinking and Human-Centered Design to Development of Intervention Implementation Strategies: An Example from Adolescent Health Research. *Journal of Public Health Research*. 9(4):jphr.2020.1746. doi:10.4081/jphr.2020.1746.

Tellez M, Zini A, Estupiñan-Day S. 2014. Social Determinants and Oral Health: An Update. *Curr Oral Health Rep*. 1(3):148–152. doi:10.1007/s40496-014-0019-6.

Torres PJ, Phan HT, Bojorquez AK, Garcia-Godoy F, Pinzon LM. 2021. Minimally Invasive Techniques Used for Caries Management in Dentistry. A Review. *J Clin Pediatr Dent*. 45(4):224–232. doi:10.17796/1053-4625-45.4.2.

Toth M, Martin Palmer L, Bercaw L, Johnson R, Jones J, Love R, Voltmer H, Karon S. 2020. Understanding the Characteristics of Older Adults in Different Residential Settings: Data Sources and Trends. U.S. Department of Health and Human Services. Office of the Assistant Secretary for Planning and Evaluation. [accessed 2024 Apr 18]. <https://aspe.hhs.gov/reports/understanding-characteristics-older-adults-different-residential-settings-data-sources-trends-0>.

Turton B, Alqunaybit G, Tembhe A, Qari A, Rawal K, Mandel E, Calabrese J, Henshaw M. 2024. Estimation of Oral Disease Burden among Older Adults in LTC: A Scoping Review. *International Journal of Environmental Research and Public Health*. 21(3):248. doi:10.3390/ijerph21030248.

Turton B, Griffith J. 2024 Jan 23. Estimating Effects of Caries Progression among Older Adults in Long-Term Care. doi:10.17605/OSF.IO/7SZ4Y. [accessed 2024 Apr 24]. <https://osf.io/7sz4y/>.

[VS] Ventana Systems. 2023. Vensim® Personal Learning Edition. Version 10.1.0. Ventana Systems, Inc. [accessed 2024 Apr 17]. <https://vensim.com/vensim-personal-learning-edition/>.

Whelan J, Fraser P, Bolton KA, Love P, Strugnell C, Boelsen-Robinson T, Blake MR, Martin E, Allender S, Bell C. 2023. Combining systems thinking approaches and implementation science constructs within community-based prevention: a systematic review. *Health Res Policy Syst*. 21(1):85. doi:10.1186/s12961-023-01023-4.

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Author Contributions

Bathsheba Turton: contributed to conception, design, acquisition, analysis, interpretation, drafted the manuscript, and critically revised the manuscript.

Jennifer Griffith: contributed to design, analysis, interpretation, drafted the manuscript, and critically revised the manuscript.

Judith Jones: contributed to interpretation and critically revised the manuscript.

Sarah Baker: contributed to conception, interpretation, and critically revised the manuscript.

Ankur Singh: contributed to interpretation, and critically revised the manuscript.

Kadambari Rawal: contributed to conception, interpretation, and critically revised the manuscript.

Joseph Calabrese: contributed to conception, interpretation, and critically revised the manuscript.

Michelle Henshaw: contributed to conception, design, acquisition, interpretation, and critically revised the manuscript.

All authors gave their final approval and agree to be accountable for all aspects of the work.

Figures and Tables

Table 1 – System dynamics model variables and assumptions

Figure 1 – System dynamics model of caries progression among dentate older adults in LTC.

Figure 2 – Proportion of dentate older adults in LTC with one or more untreated carious lesions by scenario

Table 2 – Proportion of dentate individuals in each caries severity state over a five-year period by intervention scenario.

Figure 3 – Projected impact of interventions on the distribution of caries severity states after a five-year period.

Supplemental Files

Example Patient Stories

Appendix Table 1- Dental service utilization at the on-site dental clinic at one LTC in Boston, Massachusetts among dentate older adults that received at least one dental service in 2019

Appendix Table 2 - Vensim System Dynamics Model Equations

Appendix Table 3 – Deterministic Sensitivity Analysis of System Dynamics