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Health, financial and environmental impacts of unnecessary vitamin D testing: a triple bottom line assessment adapted for healthcare

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ABSTRACT

Objective To undertake an assessment of the health, financial and environmental impacts of a well-recognised example of low-value care; inappropriate vitamin D testing.

Design Combination of systematic literature search, analysis of routinely collected healthcare data and environmental analysis.

Setting Australian healthcare system.

Participants Population of Australia.

Outcome measures We took a sustainability approach, measuring the health, financial and environmental impacts of a specific healthcare activity. Unnecessary vitamin D testing rates were estimated from best available published literature; by definition, these provide no gain in health outcomes (in contrast to appropriate/necessary tests). Australian population-based test numbers and healthcare costs were obtained from Medicare for vitamin D pathology services. Carbon emissions in kg CO_2e were estimated using data from our previous study of the carbon footprint of common pathology tests. We distinguished between tests ordered as the primary test and those ordered as an add-on to other tests, as many may be done in conjunction with other tests. We conducted base case (8% being the primary reason for the blood test) and sensitivity (12% primary test) analyses.

Results There were a total of 4 457 657 Medicare-funded vitamin D tests in 2020, on average one test for every six Australians, an 11.8% increase from the mean 2018–2019 total. From our literature review, 76.5% of Australia's vitamin D tests provide no net health benefit, equating to 3 410 108 unnecessary tests in 2020. Total costs of unnecessary tests to Medicare amounted to >$A87 000 000. The 2020 carbon footprint of unnecessary vitamin D tests was 28 576 kg (base case) and 42 012 kg (sensitivity) CO_2e, equivalent to driving ~160 000–230 000 km in a standard passenger car.

Conclusions Unnecessary vitamin D testing contributes to avoidable CO_2e emissions and healthcare costs. While the footprint of this example is relatively small, the potential to realise environmental cobenefits by reducing low-value care more broadly is significant.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This is the first study to undertake an adapted triple bottom line assessment of a low-value healthcare activity to explore and make explicit its health, financial and environmental impacts.
⇒ Our triple bottom line assessment of vitamin D testing highlights that low-value care, which provides little or no gain in health outcomes, adds significant financial costs, and contributes avoidable CO_2e emissions.
⇒ Reducing low-value care is an opportunity to reduce carbon emissions and expenditure on healthcare without adversely affecting quality of care or patient outcomes; this is an important consideration in achieving healthcare sustainability.
⇒ Unnecessary tests or inappropriate testing is a surrogate measure of health impact, rather than a direct measure.
⇒ Our estimate of carbon emissions is specific to Australia and estimates will be different in other countries depending on local electricity sources and supply chains.
⇒ Other environmental impacts, such as emissions of PM2.5, which contribute to air pollution, have not been included in our analysis.

INTRODUCTION

Healthcare has a significant carbon footprint, with 36 major countries responsible for 4.4% of annual global CO_2e emissions.[1] In England, Australia and the USA, healthcare is responsible for 3%, 7% and 10% of national CO_2e emissions, respectively.[1–3] This demonstrates the urgent need for rapid decarbonisation of the health sector, and the National Health Service (NHS) has led the world in this endeavour.[4] Further reductions, however, will require changes to clinical care, with much of the NHS gains to date coming from reduced reliance on coal and oil for on-site heating, and the decarbonisation of the UK electricity grid.[4] Yet, the evidence base for changes to clinical care that will reduce carbon emissions, without adversely impacting quality of care and healthcare costs, is limited. Previous studies of interventions to reduce the carbon footprint of clinical care have focused on reducing waste, recycling and reusing equipment,[5 6] in line with standard principles of environmental sustainability (avoid, reduce, reuse, recycle). In many clinical areas, however, reusing and recycling opportunities are limited.[7] The opportunity to reduce emissions through avoidance and reduction has been largely unexplored to date.

An acceleration in decreasing carbon emissions could be achieved by reducing low-value care, which is estimated to comprise around 30% of all healthcare.[8] Unnecessary testing, a significant contributor to low-value care, can lead to a cascade of additional unneeded testing, overdiagnosis and potentially harmful overtreatment.[9 10] Unnecessary testing may therefore lead to patient harms, financial costs to individuals and the community and preventable carbon emissions.[11 12] In the business sector, the triple bottom line has been used for over two decades to go beyond simply examining profit and loss (the primary purpose of business), and make explicit and visible the full financial, environmental and social costs of an activity.[13] This sustainability framework has been little considered in healthcare,[14] and not used extensively beyond specific policy and planning applications.[15] Yet, it could easily be adapted to consider the health (as the primary purpose of healthcare), economic and environmental impacts of clinical care. As in business, it could be used to make explicit the true 'costs' of healthcare, including the 'true' costs to individuals and to society of unnecessary testing. For the purpose of this study's example, we opted to substitute the 'social domain' of the triple bottom line approach with a health outcome. Health encompasses physical, psychological, emotional and social elements,[16] making it a more practical concept to measure in healthcare rather than the social measure traditionally used in the business triple bottom line framework. We do acknowledge in advance, however, that our health domain only covers the clinical health outcomes for our low-value healthcare example.

Vitamin D testing may be an exemplar of an opportunity to reduce the carbon footprint of healthcare associated with low-value care. There is currently no sufficient evidence of health benefits and harms of testing vitamin D levels.[17–24] Vitamin D testing is indicated in individuals at particularly high risk of abnormal vitamin D levels or related complications, including patients with osteoporosis, hyperparathyroidism, malabsorption, chronic renal failure, or hypocalcaemia or hypercalcaemia, and patients with severe lack of sun exposure or who use medications that reduce vitamin D levels.[25 26] Testing healthy individuals who are not at risk of vitamin D deficiency is not recommended as it wastes resources and can likely lead to unnecessary treatment in a significant subgroup of healthy individuals.[25] Most medical authorities, including the US Preventive Services Task Force,[27] the National Institute for Health and Care Excellence[28] and the Royal College of Pathologists of Australasia,[25] do not recommend vitamin D deficiency screening. Nevertheless, vitamin D testing rates are high and have been increasing in recent years across multiple countries, including in the UK, where there has been a 10-fold increase in vitamin D testing since 2001.[29] A Swiss study found that vitamin D levels were tested in 14% of a large nationally representative sample in 2015 and 20% in 2018, with the increase in testing occurring both in all age groups and low-risk patients (among whom testing likely provided no net health benefit).[30] In Australia, persistent rises in vitamin D testing rates between 2000 and 2013 led to the introduction of new criteria for financial rebates via the universal insurer, the Medicare Benefits Schedule (MBS), in November 2014. The new criteria were intended to discourage testing in low-risk people while still allowing testing in those at particular risk of vitamin D deficiency.[31] While initially successful (2014–2016 rates were 47% lower compared with 2013–2014 rates), testing rates have again risen in more recent years (by 34% between 2015 and 2019).[31] This increase is not explained by demographic variations or changes in clinical factors, which suggests unnecessary testing and the lack of clinician support or awareness in regard to the MBS criteria.[31]

Our aim in this study was to estimate the health, financial and environmental impacts of unnecessary vitamin D testing as a demonstration case of the use of an adapted triple bottom line approach to make explicit the full costs to the community of this example of low-value care.

METHODS

Overview

While vitamin D testing provides health benefits to some patients, many studies have shown that a proportion of vitamin D tests provide no health benefit (see below). We used the logic of the triple bottom line approach to estimate the financial and environmental impacts of these vitamin D tests of no net health value; that is, the size of our health outcome was set to zero. As such, our measure of health impact was the annual number of 'unnecessary' vitamin D tests (delivering zero health gain to patients) conducted in Australia in 2020; our measure of financial impact was the annual cost of these tests in $A to Medicare (the Australian Government universal insurer); and our measure of the environmental impact was the annual carbon emissions in kg CO_2e (also expressed as kilometre driven in a standard passenger car). For context, we calculated the total financial cost and carbon emissions of all vitamin D tests in Australia in 2020.

Patient and public involvement

No patients were involved in this study.

Health impact (zero): estimating the proportion and number of vitamin D tests with no net health benefit (unnecessary tests)

To estimate the *proportion* (*percentage*) of vitamin D tests that provide no net health benefit, we conducted a rapid evidence review of peer-reviewed studies which provided an estimate of the proportion of inappropriate or unnecessary vitamin D tests (see table 1 for how this was

Table 1 Studies reporting on the number of unnecessary vitamin D tests ordered in primary care

Study authors (year)	Study title	Country	Study type	Year of data collection	Unnecessary tests % (95% CI)	Definition for unnecessary/ providing no net health benefit
Gonzalez-Chica *et al* (2019)[20]	Changes to the frequency and appropriateness of vitamin D testing after the introduction of new Medicare criteria for rebates in Australian general practice: evidence from 1.5 million patients in the NPS Medicine Insight database	Australia	Dynamic cohort study	2016	76.5 (N/A)	Tests not meeting any of the new MBS criteria.
Woodford *et al* (2018)[19]	Vitamin D: too much testing and treating?	UK	Retrospective descriptive study	2017	70.4–77.5 (N/A)	Indication of test (known appropriateness, uncertain, not clearly justified).
Patel *et al* (2020)[17]	Reducing vitamin D requests in a primary care cohort: a quality improvement study	UK	Pre-post interventional study	2016–2017	36.2 (N/A)	The reduction in tests ordered following an intervention to reduce inappropriate test ordering.
Ferrari and Prosser (2016)[18]	Testing vitamin D levels and Choosing Wisely	Canada	Pre-post interventional study	2015	92.0 (N/A)	The reduction in tests ordered following an intervention to reduce inappropriate test ordering.
Naugler *et al* (2017)[21]	Implementation of an intervention to reduce population-based screening for vitamin D deficiency: a cross-sectional study	Canada	Cross-sectional study	2015	91.4 (N/A)	The reduction in tests ordered following an intervention to reduce inappropriate test ordering.
Rodd *et al* (2018)[22]	Increased rates of 25-hydroxyvitamin D testing: dissecting a modern epidemic	Canada	Retrospective descriptive study	2013	65.2 (64.4 to 66.0)	Whether patients had apparent reason for test (followed consensus guidelines and clinical expertise to define what is appropriate).
Felcher *et al* (2017)[23]	Decrease in unnecessary vitamin D testing using clinical decision support tools: making it harder to do the wrong thing	USA	Retrospective descriptive study	2014	43.8 (N/A)	The reduction in tests ordered following an intervention to reduce inappropriate test ordering.
Petrilli *et al* (2018)[24]	Reducing unnecessary vitamin D screening in an academic health system: what works and when	USA	Pre-post interventional study	2015–2016	37.0 (N/A)	No high-risk condition identified in the year prior to test ordering.

MBS, Medicare Benefits Schedule; N/A, not applicable.

defined by each study). We searched the following databases: Scopus, ScienceDirect and PubMed. We used the following search terms: 'vitamin d test*' OR 'vit d test*' OR 'pathology test' OR 'vitamin d screening' OR 'vit d screening' OR 'vitamin d deficien*' OR 'vit d deficien*' AND 'unnecessary' OR 'unneeded' OR 'avoidable' OR 'avoid' OR 'excess' OR 'inessential' OR 'reduce' OR 'too much'.

Papers were considered if peer reviewed, and published in the past 10 years (between January 2011 and 2021). We included both international and country-specific papers published in English. We first screened titles and abstracts, and articles were then evaluated in full to ensure relevance to our focus of estimating the proportion of inappropriate/unnecessary vitamin D testing in community (primary care) settings. This search was complemented with forward and backward citation searches of included articles (see online supplemental figure 1 for complete search results displayed in a Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram).

Results were heterogeneous so we did not pool them in meta-analysis. Instead, we used the best, most applicable (to the Australian population and context) estimate and applied this proportion to the absolute number of vitamin D tests conducted in Australia in 2020 (see below).

Determining vitamin D test numbers

To determine the number of vitamin D tests ordered in Australia, we obtained Medicare Item Reports for current vitamin D pathology services for 25-hydroxyvitamin D or 1,25-dihydroxyvitamin D quantification in serum (MBS item numbers 66833, 66834, 66835, 66836 and 66837).[32]

We obtained the total testing counts and rates (per 100 000 population) for each item number from November 2014 (when the current items were first introduced) until December 2020. We averaged the monthly data from 2018 and 2019, and compared these averages to the 2020 data, both nationally and across all Australian states and territories.

Financial impact

We calculated the total 2019 and 2020 financial costs to the Australian Government, based on Medicare rebates of the vitamin D tests under the MBS (Medicare Benefits Schedule). These rebate amounts are set by the Australian Government as costs paid to providers for medical services.[33] We obtained publicly available cost data for all vitamin D testing (MBS item numbers 66833, 66834, 66835, 66836 and 66837) (the different item numbers are for billing by different providers, a general practitioner or a specialist, and whether or not the test is done as part of managing treatment of related conditions such as hyperparathyroidism or hypercalcaemia).[34]

Environmental impact

To calculate the *carbon footprint of vitamin D testing* in Australia, we used data from our previous study of the carbon footprint of common pathology tests.[7] The emissions measured were solely the carbon arising from the plastic and electricity required to run vitamin D tests. We did not include all the compounding 'cascade' impacts that flow from performing a vitamin D test providing no net health benefit,[35] such as buying vitamin D supplements, additional bone scans and coming back for repeat vitamin D testing.

We distinguished between tests ordered as the primary test and those ordered as an add-on to another test, as vitamin D is often requested as an 'add on' test. The marginal carbon footprint of add-on tests is less than tests ordered as the primary test; for example, the carbon footprint for a primary vitamin D test is 99 g CO_2e, but when performed as an add-on test is 0.5 g CO_2e.[7] We conducted base case and sensitivity analyses of 2020 data. The base case and sensitivity analyses assumed 8% and 12%, respectively, of vitamin D tests were ordered as the primary reason for the blood test, from reasons reported for vitamin D test ordering in Australian general practice.[36] We also conducted a second analysis using 2019 data to allow for the possibility that the appropriateness of vitamin D testing may have been affected by the COVID-19 pandemic. We present the results in kg CO_2e and as kilometres driven in an Australian standard passenger car.[37]

RESULTS

Proportion of vitamin D tests which provide no net health benefit (unnecessary tests)

We identified eight studies that estimated the proportion (%) of vitamin D tests that are unnecessary or inappropriate. These studies, their definitions of unnecessary or inappropriate testing and their results are summarised in table 1. The proportion of tests considered unnecessary varied between 36.2% (in the UK) and 92.0% (in Canada),[17,18] depending on the way 'unnecessary testing' was defined and operationalised and on the context (country and clinical setting). For example, a 2017 study in the UK found that 70.4%–77.5% of vitamin D tests were potentially inappropriate, depending on whether or not falls and osteoporosis were justified as appropriate reasons for testing.[19] Another more recently published UK study reported a 36.2% reduction in the number of vitamin D tests ordered following the introduction of an electronic laboratory request form, an intervention to reduce the number of unnecessary tests, indicating that at least 36.2% of the tests ordered pre-implementation were likely unnecessary.[17]

Only one study quantified the number of vitamin D tests providing no net health benefit in Australia.[20] This study looked at whether the changes introduced in 2013 to restrict rebates for vitamin D testing to a set of relevant clinical indications had resulted in less unnecessary testing. Their robust methodology involved comparing the vitamin D test results from the NPS Medicine Wise Insights database for a large, representative sample of more than 1.5 million patients and patients' clinical data from the same database against the revised Medicare indications. They used a computer algorithm to do this comparison to determine the percentage that was performed with no medical indication for being done (ie, they were unnecessary with net zero health benefit). The study found that 76.5% of vitamin D tests conducted in 2016 met none of the clinical indications for the test. This was an unexpected increase from 71.3% in 2013 before the restrictions had been implemented, but was consistent with vitamin D testing rates which, following an initial drop, had returned to 2013 levels and then continued to grow. These studies displayed considerable heterogeneity, so we did not pool the results. Instead, we used the Australian estimate of 76.5% of vitamin D tests providing no net health benefit for our analyses.[20] Due to its strong methodology, its applicability to our research question and because it is a recent and local (Australian-based) estimate, we have confidence that the estimate of 76.5% net zero health benefit is valid and appropriate for our Australian study and reflects current clinical practice.

Vitamin D test numbers

A total of 4 457 657 vitamin D tests were done in 2020, an 11.8% increase from the average annual rate in 2018 and 2019 (3 987 644 tests) (figure 1).

During 2020, there were visible declines in testing that coincided with Australia's national public health 'stay at home' orders in response to COVID-19 from late March until mid-May, and a further 'stay at home' order in the state of Victoria in the second half of 2020 (see online supplemental figure 2). Despite these impacts of the pandemic, total tests conducted in 2020 surpassed the total for previous years, and data for the first half of 2021 show a further increase in monthly testing numbers (data not shown).

Triple bottom line results

Triple bottom line results are shown in table 2.

Health impact; zero net health benefit

Of the total 4 457 657 vitamin D tests conducted, 3 410 108 (76.5%) delivered no health benefit to patients.

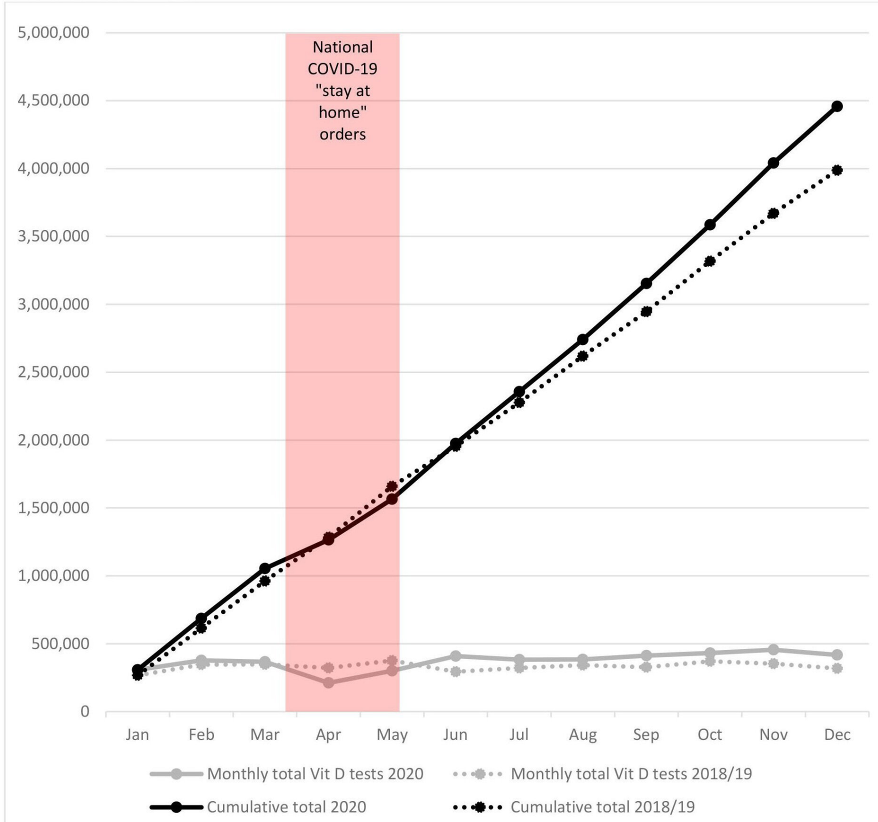

Figure 1 Australia's vitamin D monthly* and cumulative test numbers in 2020 compared with 2018/2019 averages. (*For more details, please view online supplemental figure 2, showing Australia's monthly vitamin D test rates.)

Financial impact

In 2020, the total cost to Medicare of vitamin D tests providing no net health benefit was \$87 229 690, and the cost of all vitamin D tests combined was \$114 025 739. In 2019, these financial costs were \$79 909 161 for vitamin tests providing no net health benefit, and \$104 456 420 for all vitamin D tests combined.

Environmental impact

Carbon emissions from vitamin D tests providing no net health benefit were 28 576 kg CO_2e, equivalent to driving from Sydney (SYD) to Perth (PER) 40 times (157 970 km travelled in a standard passenger car). In the sensitivity analysis, carbon emissions from unnecessary tests were 42 012 kg CO_2e, equivalent to driving SYD-PER 59 times (232 242 km travelled in a standard passenger car). The carbon emissions from all 2020 vitamin D tests were 37 355 kg CO_2e (54 918 kg CO_2e in sensitivity analysis).

The results of the secondary analysis using 2019 testing data were 26 172 kg CO_2e (base case analysis) and 38 477 kg CO_2e (sensitivity analysis).

Table 2 Triple bottom line showing the impact of vitamin D tests providing no net health benefit in Australia, 2020 (and of total vitamin D tests)

Health impact (zero)	**Financial impact Cost to Medicare (\$A)**	Environmental impact Carbon footprint (kg CO_2e) Base case analysis **(**8% ordered as primary test, 92% add-on test**)**	Environmental impact Carbon footprint **(**kg CO_2e**)** Sensitivity analysis (12% ordered as primary test, 88% add-on test**)**
Vitamin D tests providing no net health benefit			
3 410 108	\$87 229 690	28 576 kg CO_2e Equivalent to driving SYD-PER 40 times (157 970 km travelled in a standard passenger car)	42 012 kg CO_2e Equivalent to driving SYD-PER 59 times (232 242 km travelled in a standard passenger car)
Total vitamin D tests			
4 457 657	\$114 025 739	37 355 kg CO_2e Equivalent to driving SYD-PER 52.5 times (206 496 km travelled in a standard passenger car)	54 918 kg CO_2e Equivalent to driving SYD-PER 77 times (303 584 km travelled in a standard passenger car)

SYD-PER, Sydney to Perth.

DISCUSSION

Statement of principal findings

Our triple bottom line assessment highlights the large number of vitamin D tests providing no net health benefit (>3 million per year) conducted in Australia. In 2020, these unnecessary tests incurred a financial cost to the Australian Government of over $87 million and a carbon burden equivalent to 28 000–42 000 kg CO_2e or driving approximately 160 000–230 000 km in a standard, petrol-fuelled, passenger car, while delivering no health benefit. The results of our second analysis using 2019 data followed the same pattern, showing that using prepandemic data makes no difference to the overall picture of the true costs of these unnecessary tests. Furthermore, we found that the total number of vitamin D tests (necessary and unnecessary) conducted annually in Australia is inexplicably large for a population with abundant sun exposure. In a total population of 25 694 393, we found there is on average one vitamin D test conducted for every six Australians per year.[38]

Strength and limitations

To our knowledge, this is one of the first studies to undertake an adapted triple bottom line assessment of a health intervention to explore and make explicit its health, financial and environmental impacts,[14] and the first to use this approach in the context of a low-value care example. This demonstration case may help raise awareness of the opportunity to generate environmental benefits by reducing acknowledged sources of unnecessary or low-value care, including overtesting and consequent overtreatment. Given that efforts to date to reduce low-value care in general, and unnecessary testing specifically, have been met with only limited success, triple bottom line assessments may help by using carbon emission reduction targets to provide additional motivation and incentive for change by underscoring the environmental cobenefits of reducing low-value care. As low-value care represents approximately 30% of total healthcare,[8] the potential to realise environmental cobenefits is significant.

Our estimates of the carbon emissions and costs that could be saved by eliminating unnecessary vitamin D tests are likely underestimates. Internationally, up to 92% of vitamin D tests may be providing no net health benefit,[18] and the estimate of 76.5% for unnecessary vitamin D tests in Australia was based on 2016 data.[20] Testing rates in Australia have continued to rise, with likely an even higher proportion providing no net health benefit. Furthermore, we have included only tests rebated by Medicare, and some tests are not rebatable, including those done on individuals (non-permanent residents) who are not covered by Medicare, and tests done through some private enterprises (eg, naturopaths). Second, as demonstrated by our sensitivity analysis, the carbon footprint will depend heavily on the proportion of vitamin D tests that are ordered as the principal reason for ordering a pathology test in that episode of care. While vitamin D tests are rarely ordered in isolation (we assumed only 8% was the primary reason in our base case), it is hard to judge which test motivates test ordering when vitamin D tests are co-ordered with other tests, and we found little data to guide our estimates. In our sensitivity analysis, we increased the proportion of vitamin D tests being ordered primarily for vitamin D level (rather than being an additional co-ordered test) to 12% based on reported reasons for vitamin D test ordering in Australian primary care practice.[36] However, anecdotal evidence from general practitioner colleagues suggests that these proportions may be much higher, with one reason being the sustained recent interest in vitamin D testing (and supplementation) prevalent in the professional and lay community.

Our study has limitations. Our dichotomy of unnecessary/necessary tests relies on the definitions and assessments made by study authors to underpin the estimates of unnecessary testing reported in table 1, and there is variation internationally from 36% to 92% of vitamin D tests being unnecessary or inappropriate. However, the estimate of the proportion of unnecessary tests that we used is based on a high-quality study and is directly applicable to our study context. Our literature review demonstrates that there is a global acceptance that unnecessary vitamin D testing occurs and is common; it seems reasonable to conclude there is no net health benefit from these unnecessary vitamin D tests. We acknowledge also that our measure of health impact focuses on the clinical effectiveness and physical health, and omits other aspects of health (ie, social, psychological and emotional health).[16] Thus, we recommend that future research adapting the triple bottom line approach in healthcare should endeavour to further broaden the social/health domain. Furthermore, we acknowledge that unnecessary tests are a surrogate measure or proxy for health impact, rather than a direct measure. We note, however, that national guidelines recommend against population testing or screening because evidence of health benefit from vitamin D testing is lacking,[27 28] and that high-quality evidence does not support an association between vitamin D supplementation and improvements in fatigue, depression, chronic pain and osteoarthritis,[39–43] or reductions in the risk of developing cancer, diabetes or bone fractures.[43]

Our analysis is specific to Australia. Using proportions of vitamin D tests that are unnecessary in other jurisdictions would result in different estimates of costs and carbon emissions in those jurisdictions. Importantly, our estimate of carbon emissions is specific to Australia, as our estimate of the carbon footprint of pathology tests was conducted in Australia,[7] and therefore is reliant on Australian electricity supply and on emissions of medical products used in Australia, which will be different in different countries. We note that there are additional, unmeasured environmental impacts arising from testing, such as clinical waste and air and water pollution. While important, these are beyond the scope of the present study.

Importance of our results in relation to other studies

Despite recommendations against vitamin D screening or population testing in guidelines,[25 27 28 44] and by advocacy groups such as Choosing Wisely,[26 45–47] vitamin D testing at high rates persists. Our finding that vitamin D testing rates continued to grow over 2020 is consistent with a recent US study,[48] which found that prescriptions for vitamin D supplements increased by 9.9% over the previous year, peaking in March 2020 when the USA declared a national emergency due to COVID-19. These changes could potentially be due to the high prevalence of misinformation and controversy around COVID-19 and vitamin D,[49] including misplaced beliefs that vitamin D testing and supplementation might be of benefit in preventing and treating COVID-19 despite guidance and randomised trials to the contrary.[50–54]

The financial costs of vitamin D testing are considerable to health systems. The total cost of vitamin D tests in the UK increased from £1 to £17 million between 2001 and 2018, not including the indirect costs of testing and appointments paid for by individuals. In Australia, vitamin D testing was estimated to cost $1.1 million to Medicare in 2000, rising to $105 million in 2019.[31] We have demonstrated a further increase to $114 million in 2020, of which $87 million was incurred from testing providing no net health benefit.

Implications

Our adapted triple bottom line assessment provides compelling evidence that unnecessary vitamin D testing is common and costly in financial terms and carbon emissions while delivering no health gains for patients. This case study is just one example of low-value care, and impacts would be much greater for low-value care more broadly. Triple bottom line assessments like this one could provide a more comprehensive picture of the total costs to society of low-value care and may help strengthen and accelerate the decarbonisation of healthcare. There may be opportunities for policy documents (eg, guidelines) and practice initiatives (eg, Choosing Wisely) to augment their messages with salient information about the environmental impact of unnecessary and low-value care. Triple bottom line assessments done in other jurisdictions and for other clinical care activities based on local testing rates, financial costs, and carbon emissions would be of value as each of the triple bottom line components will vary between countries, regions and health systems.

Unanswered questions

It remains unknown and untested to date whether information about the environmental impact of unnecessary testing (in addition to information about effects on health and health sector costs) will provide additional motivation for clinicians, policy makers and patients to reduce low-value care. Furthermore, factors underlying the persistent trend towards apparently ever higher vitamin D testing in particular warrant exploration.

CONCLUSION

High rates of unnecessary vitamin D tests in Australia represent low-value care, wasted resources and avoidable carbon emissions for no gain in health outcomes. Reducing unnecessary health services is a cost-saving approach to decreasing the carbon footprint of healthcare and deserves additional attention in policy, practice and future research.

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Contributors AB and KB conceived the study. MB-P, AB, KB, FM, KP and SM were all involved in designing the study and developing the methods. AB obtained funding. AB and KB coordinated the running of the study. MB-P, KP and KB conducted the rapid evidence review. MB-P conducted the data collection. MB-P and AB conducted the analysis. MB-P and AB drafted the manuscript. All authors (MB-P, AB, KB, FM, KP, SM) critically revised the manuscript. AB and MB-P are guarantors of the study.

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REFERENCES

1. Pichler P-P, Jaccard IS, Weisz U, *et al*. International comparison of health care carbon footprints. *Environmental Research Letters* 2019;14:064004.
2. Eckelman MJ, Sherman J. Environmental impacts of the U.S. health care system and effects on public health. *PLoS One* 2016;11:e0157014.
3. Malik A, Lenzen M, McAlister S, *et al*. The carbon footprint of Australian health care. *Lancet Planetary Health* 2018;2:e27–35.
4. Tennison I, Roschnik S, Ashby B, *et al*. Health care's response to climate change: a carbon footprint assessment of the NHS in England. *Lancet Planet Health* 2021;5:e84–92.

5 Thiel CL, Woods NC, Bilec MM. Strategies to reduce greenhouse gas emissions from laparoscopic surgery. *Am J Public Health* 2018;108:S158–64.
6 Thiel CL, Eckelman M, Guido R, *et al*. Environmental impacts of surgical procedures: life cycle assessment of hysterectomy in the United States. *Environ Sci Technol* 2015;49:1779–86.
7 McAlister S, Barratt AL, Bell KJ, *et al*. The carbon footprint of pathology testing. *Med J Aust* 2020;212:377–82.
8 Braithwaite J, Glasziou P, Westbrook J. The three numbers you need to know about healthcare: the 60-30-10 challenge. *BMC Med* 2020;18:102.
9 Bell KJL, Doust J, Glasziou P, *et al*. Recognizing the potential for overdiagnosis: are high-sensitivity cardiac troponin assays an example? *Ann Intern Med* 2019;170:259–61.
10 Brownlee S, Chalkidou K, Doust J, *et al*. Evidence for overuse of medical services around the world. *The Lancet* 2017;390:156–68.
11 Barratt A, McGain F. Overdiagnosis is increasing the carbon footprint of healthcare. *BMJ* 2021;375:n2407.
12 Barratt AL, Bell KJ, Charlesworth K, *et al*. High value health care is low carbon health care. *Med J Aust* 2022;216:67–8.
13 Elkington J. 25 years ago I coined the phrase “triple bottom line.” Here’s why it’s time to rethink it. *Harvard Business Rev* 2018;25:2–5.
14 Vergunst F, Berry HL, Rugkåsa J, *et al*. Applying the triple bottom line of sustainability to healthcare research-a feasibility study. *Int J Qual Health Care* 2020;32:48–53.
15 Duane B, Taylor T, Stahl-Timmins W, *et al*. Carbon mitigation, patient choice and cost reduction – triple bottom line optimisation for health care planning. *Public Health* 2014;128:920–4.
16 World Health Organization. Constitution. Geneva, World Health Organisation 1948.
17 Patel V, Gillies C, Patel P, *et al*. Reducing vitamin D requests in a primary care cohort: a quality improvement study. *BJGP Open* 2020;4:bjgpopen20X1010
18 Ferrari R, Prosser C. Testing vitamin D levels and choosing wisely. *JAMA Intern Med* 2016;176:1019.
19 Woodford HJ, Barrett S, Pattman S. Vitamin D: too much testing and treating? *Clin Med* 2018;18:196–200.
20 Gonzalez-Chica D, Stocks N, Nigel S. Changes to the frequency and appropriateness of vitamin D testing after the introduction of new Medicare criteria for rebates in Australian general practice: evidence from 1.5 million patients in the NPS MedicineInsight database. *BMJ Open* 2019;9:e024797.
21 Naugler C, Hemmelgarn B, Quan H, *et al*. Implementation of an intervention to reduce population-based screening for vitamin D deficiency: a cross-sectional study. *CMAJ Open* 2017;5:E36–9.
22 Rodd C, Sokoro A, Lix LM, *et al*. Increased rates of 25-hydroxy vitamin D testing: dissecting a modern epidemic. *Clin Biochem* 2018;59:56–61.
23 Felcher AH, Gold R, Mosen DM, *et al*. Decrease in unnecessary vitamin D testing using clinical decision support tools: making it harder to do the wrong thing. *J Am Med Inform Assoc* 2017;24:776–80.
24 Petrilli CM, Henderson J, Keedy JM, *et al*. Reducing unnecessary vitamin D screening in an academic health system: what works and when. *Am J Med* 2018;131:1444–8.
25 The Royal College of Pathologists of Australasia. Use and interpretation of vitamin D testing, 2019. Available: https://www.rcpa.edu.au/Library/College-Policies/Position-Statements/Use-and-Interpretation-of-Vitamin-D-Testing
26 Choosing Wisely Australia. Recommendations: the Royal College of Pathologists of Australasia, 2015. Available: https://www.choosingwisely.org.au/recommendations/rcpa
27 US Preventive Services Task Force, Krist AH, Davidson KW, *et al*. Screening for vitamin D deficiency in adults: US preventive services task force recommendation statement. *JAMA* 2021;325:1436–42.
28 National Institute for Health and Care Excellence. *Vitamin D: supplement use in specific population groups*, 2017.
29 Bolland MJ, Avenell A, Smith K, *et al*. Vitamin D supplementation and testing in the UK: costly but ineffective? *BMJ* 2021;372:n484.
30 Essig S, Merlo C, Reich O, *et al*. Potentially inappropriate testing for vitamin D deficiency: a cross-sectional study in Switzerland. *BMC Health Serv Res* 2020;20:1-1097.
31 Gordon L, Waterhouse M, Reid IR, *et al*. The vitamin D testing rate is again rising, despite new MBS testing criteria. *Med J Aust* 2020;213:155-.e1:155.
32 Australian Government Human Services. Medicare item reports, 2021. Available: http://medicarestatistics.humanservices.gov.au/statistics/mbs_item.jsp
33 Australian Government Department of Health. Medicare benefits schedule online - Note GN.10.26, 2021. Available: http://www9.health.gov.au/mbs/fullDisplay.cfm?type=note&q=GN.10.26&qt=noteID
34 Australian Government Department of Health. Medicare benefits schedule - item 66833, 2021. Available: http://www9.health.gov.au/mbs/fullDisplay.cfm?type=item&q=66833&qt=ItemID
35 Rockwell MS, Wu Y, Salamoun M, *et al*. Patterns of clinical care subsequent to nonindicated vitamin D testing in primary care. *J Am Board Fam Med* 2020;33:569–79. 1;.
36 Tapley A, Magin P, Morgan S, *et al*. Test ordering in an evidence free zone: Rates and associations of Australian general practice trainees’ vitamin D test ordering. *J Eval Clin Pract* 2015;21:1151–6.
37 National Transport Commission. Carbon dioxide emissions intensity for new Australian light vehicles 2019, 2019. Available: https://www.ntc.gov.au/sites/default/files/assets/files/Carbon-dioxide-emissions-intensity-for-new-Australian-light-vehicles-2019.pdf
38 Australian Bureau of Statistics. National, state and territory population 2021. Available: https://www.abs.gov.au/statistics/people/population/national-state-and-territory-population/dec-2020
39 Gowda U, Mutowo MP, Smith BJ, *et al*. Vitamin D supplementation to reduce depression in adults: meta-analysis of randomized controlled trials. *Nutrition* 2015;31:421–9.
40 Bertone-Johnson ER, Powers SI, Spangler L, *et al*. Vitamin D Supplementation and Depression in the Women’s Health Initiative Calcium and Vitamin D Trial. *Am J Epidemiol* 2012;176:1–13.
41 Straube S, Derry S, Straube C, *et al*. Vitamin D for the treatment of chronic painful conditions in adults. *Cochrane Database Syst Rev* 2015;5:CD007771.
42 Zhang Y, Fang F, Tang J, *et al*. Association between vitamin D supplementation and mortality: systematic review and meta-analysis. *BMJ* 2019;366:l4673.
43 LeBlanc ES, Zakher B, Daeges M, *et al*. Screening for vitamin D deficiency: a systematic review for the U.S. preventive services Task force. *Ann Intern Med* 2015;162:109–22.
44 Bhadhuri A, Sutherland CS, Suter-Zimmermann K. Vitamin D testing. Health technology assessment (HTA) HTA scoping report, 2020. Available: https://edoc.unibas.ch/78859/1/20201013093317_5f85583dc6065.pdf
45 Choosing Wisely US. Vitamin D tests. When you need them-and when you don't, 2017. Available: https://www.choosingwisely.org/wp-content/uploads/2018/02/Vitamin-D-Tests-ASCP.pdf
46 Choosing Wisely Canada. Vitamin D Tests: When you need them - and when you don't, 2017. Available: https://choosingwiselycanada.org/wp-content/uploads/2017/06/Vitamin-D-EN.pdf
47 Choosing Wisely UK, Health A-Z. 2016/2018 2019, 2019. Available: https://www.choosingwisely.co.uk/i-am-a-patient-carer/health-a-z/#1528976223995-2097bf58-5569
48 Geller AI, Lovegrove MC, Lind JN, *et al*. Assessment of outpatient dispensing of products proposed for treatment or prevention of COVID-19 by US retail pharmacies during the pandemic. *JAMA Intern Med* 2021;181:869.
49 Pickles K, Cvejic E, Nickel B, *et al*. COVID-19 misinformation trends in Australia: prospective longitudinal national survey. *J Med Internet Res* 2021;23:e23805-e.
50 Murai IH, Fernandes AL, Sales LP, *et al*. Effect of a single high dose of vitamin D3 on hospital length of stay in patients with moderate to severe COVID-19: a randomized clinical trial. *JAMA* 2021;325:1053–60.
51 Pham H, Waterhouse M, Baxter C, *et al*. The effect of vitamin D supplementation on acute respiratory tract infection in older Australian adults: an analysis of data from the D-Health trial. *Lancet Diabetes Endocrinol* 2021;9:69–81.
52 National Institute for Health and Care Excellence. COVID-19 rapid guideline: vitamin D, 2020. Available: https://www.nice.org.uk/guidance/ng187
53 World Health Organisation. Coronavirus disease (COVID-19) advice for the public: Mythbusters, 2021. Available: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public/myth-busters#supplements
54 Jolliffe DA, Holt H, Greenig M. Vitamin D supplements for prevention of Covid-19 or other acute respiratory infections: a phase 3 randomized controlled trial (CORONAVIT) 2022.