

The Health And Economic Burden of Desalination-Related Magnesium Deficiency

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Introduction

Two decades ago, Israel was in the throes of a long drought. Water levels in the Kinneret, Israel's main freshwater lake, fell to just above the "black line" (below which salt infiltration, usually irreversible, would have rendered the water unusable). Public service announcements encouraging water conservation became common. Restrictions were imposed on both domestic and agricultural users, and, in general, there was considerable public anxiety due to the severe water shortage in Israel.

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Today, that water-stressed era is a mere memory. In spite of the fact that since 2000 the population has grown by more than 50%, mean annual precipitation is 9.6% lower than during the preceding 50 years, and the mean annual temperature is 1.5 Celsius higher (own estimate, using CRU data — Climate Research Unit, version 4.07), Israelis now have access to more fresh water per capita than they did in 2000. In other words, all immediate signs of an impending water crisis have evaporated.

This reversal in Israel's water fortunes is in sharp contrast to the situation in neighboring countries, where responses to the same long-term droughts that affected Israel were mismanaged, leading to collapsing water tables, to the drilling of increasingly deep wells and, ultimately, to exhausted aquifers. Many have cited that mismanagement — and the massive movement of people from rural to urban areas that it caused in countries like Syria and Iraq — as major factors driving political instability and civil war (Daoudy, 2020; DuBois King, 2016; Gleick, 2014).

Israel's success stemmed from two key sets of policies. The first was a major multi-layered conservation effort that included the installation of low-flow showers and toilets, more advanced forms of drip irrigation, and very high rates of water recapture: more than 85% of waste water is recaptured and reused, mostly as irrigation; this is more than four times the rate in Spain, considered the second-ranked high-income country on this measure (Jacobsen, 2016). Israel's water leakage rate — around 7–8%, relative to a wealthy-country average around 30% — is also considered the lowest in the world (Durst, 2020).

The main factor driving the reversal of Israel's water fortunes, however, was its decision to increase the *supply* of freshwater into the system by building a large-scale desalination infrastructure. Seven plants are currently in operation — see Table 1, part of a brief spotlight on the timing of plants — with an eighth, the Sorek B facility, scheduled to come online in the next year.

Israel's current reliance on desalination for its water needs is the starting point of this paper. In the big picture, Israel's transition to desalination has been an unambiguous triumph. Estimates from 2017 place the share of Israel's total drinking water sourced from desalination at around 70% nationally,¹ though estimates reach as high as 80% (Koren et al., 2017). Indeed, even without the Sorek B facility, Israel has begun to refill the Kinneret with its excess water. In

1 The Government Water Authority response to a request under the Freedom of Information Law, November 2023.

other words, Israel is reversing the flow of the National Water Carrier (NWC), the large pipe that once carried water from the Kinneret to all parts of the country, and is now using the Kinneret as a natural water storage facility.²

Our goal in this paper is not to diminish the success of Israel's desalination project in delinking Israel's access to water from increasingly unreliable precipitation patterns. Rather, it is to point to an area of public health where this transition may have led to somewhat undesirable — albeit *fixable* — consequences.

Here is the problem. Along with the UAE, Israel's population is the first substantial national population to consume demineralized drinking water on a large scale. In this regard, the effects of desalination need to be documented quite carefully since there is a substantial scientific literature on the health benefits of certain types of minerals that appear in naturally occurring freshwater but are removed during the desalination process.

Our empirical focus is on magnesium deficiency. Note that many others have pointed to the negative effects of transitioning to desalinated water on magnesium consumption. Our specific contribution here is that we project the health effects of this switch to desalinated, demineralized water on the incidence of two key health outcomes in Israel: type 2 diabetes (T2D), and ischemic stroke (IS). Our findings point to substantial increases in the first of these — elevating its already high levels even higher — and to a more moderate increase, in absolute terms, in the existing low incidence of ischemic stroke. We also translate these total effects of magnesium deficiency into both the marginal number of person-years in the population lived with T2D, and to the additional financial cost of the extra cases of T2D and IS to the public health system.

The key message of this research is that alongside the overwhelming triumph of supplementing Israel's very limited freshwater stocks with desalinated water, there is a public health cost. Luckily, it is an *avoidable* public health cost since, as detailed in the conclusions, magnesium can be added to desalinated water at source.

2 The success also has potentially global effects. Since Israeli scientists have been instrumental in scaling up these technologies and figuring out cleaner and more environmentally-friendly solutions to long-standing problems — a notable example is chemical-free methods to avoid the membranes becoming clogged with micro-organisms — Israeli companies are now heavily involved in the global deployment of these technologies in other arid and water-stressed areas of the world.

SPOTLIGHT

A Brief History of Desalination in Israel

Israel's first experiments with desalination were fielded in Eilat and Ashdod between the 1960s and 1980s. However, the first commercially viable "reverse osmosis" desalination plant in Israel was opened in Eilat in 1997 — the viability was made possible, in part, by the high cost of transporting water from Israel's north all the way to Eilat. A second installation, focused on brackish water in areas to the north of Caesarea, opened in Kibbutz Ma'agan Michael in 2004.

These first two plants lapped at the edges of Israel's growing water needs. They were both relatively small, with a maximum annual capacity of 38 million cubic meters, and neither desalinated pure seawater. In contrast, the Ashkelon plant, the largest in the world when it opened in 2005, had an initial capacity of around 120 million cubic meters of pure seawater. Since then, desalination plants have become bigger and, both because of economies of scale and ongoing technological innovations, are offering water at an increasingly lower price per unit.

As can be seen in Table 1, there are currently seven functional desalination plants in Israel, with an eighth, Sorek B, scheduled to open in the next year. By the time Sorek B opens, Israel's

desalination plants will have the capacity to desalinate almost a billion cubic meters of seawater per year (which is around 35% of Israel’s total water consumption, including agricultural and industrial purposes)(Kramer, 2022)

Table 1. Israel’s desalination plants

	Name/location	Opened	Capacity (m ³ /year)
1	Eilat	1997	20 million
2	Ma’agan Michael	2004	18 million [brackish water]
3	Ashkelon	2005; expanded 2010	119 million
4	Palmachim	2007	90 million
5	Hadera	2009	127 million
6	Sorek A	2013	150 million
7	Ashdod	2015	100 million
8	Sorek B*	Scheduled 2024	200 million

* The Sorek B plant, the first to be built in northern Israel, will completely change the water supplied in this area which up to now has relied on natural sources.
Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center | Data: [Water Authority](#) and [Wikipedia](#) (Hebrew)

The paper has three main sections. In the first, we summarize biomedical literature linking consumption of magnesium to health outcomes, focusing on T2D and IS. In the second, we project the effects of adding 50 mg of magnesium to Israelis’ average daily consumption. A third section discusses financial implications of this rising tide of morbidity associated with magnesium deficiency, first addressing T2D and IS. Our concluding section of the paper briefly reviews some potential fixes to this problem focusing, most notably, on the addition of magnesium in the desalination process. We argue that the cost of this intervention will be more than offset by later savings to the public health system.

Health effects of magnesium deficiency

The health effects of magnesium have been a focus of biomedical research for decades, following the early 20th century recognition that it is a critical mineral in human health. Despite this recognition, and the fact that magnesium is the second most abundant intracellular cation, it is referred to as the “forgotten” cation in human health.³ Routine blood tests — i.e., a “basic metabolic panel” — do not pick up magnesium so less is known about it across the population than other cations.

Over the last century, much more has been discovered about the mechanisms linking magnesium to the proper functioning of every organ in the body, including the bones, immune system, intestines, and cardiovascular system (de Baaij et al., 2015; Shechter & Eilat-Adar, 2021; Touyz et al., 2024). In general, its core function is to act as a cofactor in enzymatic reactions that are crucial for cellular function and metabolism. Specifically, magnesium is involved in all important biochemical and metabolic processes in the cell, such as glucose regulation, and some of the enzymatic actions that magnesium mediates are critical to life. Magnesium also plays a role in regulating the electrical properties of the heart muscle, in dilating blood vessels and relaxing smooth muscle through suppression of mechanisms that constrict blood vessels, and in suppressing inflammatory mechanisms that prevent vascular calcification and the development of atherosclerosis, thrombosis and myocardial infarction. Finally, magnesium plays a critical regulatory role in relation to other cations, in particular calcium and potassium ions. Optimal concentration of calcium in the cell plays a key role in normal blood pressure, preventing blood clots and arterial calcification, among other things. When the calcium concentration in the cell is high, there is disruption in the cellular metabolism and an increase in insulin resistance, obesity and the incidence of T2D. Recently, it has been found that calcium plays a critical role in the metabolic processes mediated by insulin, and too much calcium in the cell disrupts these processes (Kang et al., 2017). For these reasons, the body tightly controls the concentration of magnesium in the intracellular fluid.

3 A cation, also known as an “electrolyte” in the human body, is an ion with a positive charge (protons outnumber electrons). In addition to magnesium, common examples of cations in the body are sodium, potassium, and calcium.

Although it has been known for many years that diabetics suffer from magnesium deficiency, which is also associated with an increase in diabetes complications and mortality rates, empirical support causally linking magnesium deficiency to the incidence of diabetes has only recently been established (Barbagallo & Dominguez, 2007). The link works through a number of mechanisms. On the one hand, magnesium regulates insulin receptor activity and is thus involved in the metabolic effects of glucose and insulin. On the other hand, insulin is an important hormone in the metabolic regulation of magnesium in the body because it is involved in the process of transporting magnesium from the extracellular space to the intracellular space. For this reason, the lower the magnesium levels, the greater the amount of insulin required to metabolize a given amount of glucose, meaning that insulin sensitivity decreases. In addition, when the amount of magnesium in the cell is low, the ability of insulin to get the magnesium into the cell is lower. A final piece of evidence that low magnesium levels can cause diabetes is that older age is associated with both decreased cellular magnesium concentration and older adults are prone to metabolic disease and vascular diseases in general (Barbagallo et al., 2021).

The longstanding recognition that there is a positive correlation between magnesium deficiency and a number of chronic conditions has given rise to numerous studies. Over time, their focus has broadened considerably. Over the last couple of decades, they have also included carefully designed prospective studies, typically considered the gold-standard in medical research. This literature now provides strong empirical evidence linking low magnesium consumption to substantial increases in the incidence of type 2 diabetes (T2D), also known as adult-onset diabetes, and ischemic strokes (IS) (Albaker et al., 2022; Barbagallo & Dominguez, 2007; Zhao et al., 2020). Low magnesium consumption also increases mortality for those with acute coronary syndrome (ACS) (Shlezinger et al., 2018), liver disease (Wu et al., 2017), and Chronic Kidney disease (CKD) (Yin et al., 2023). The accumulating data prompted The Israel Heart Society and the Israeli Dietetic Association to issue a position paper regarding dietary recommendation of magnesium for cardiovascular prevention and treatment recommending magnesium supplementation and routine checks for patients with cardiovascular disease (Shechter & Eilat-adar, 2021).

This recognition that low magnesium has notable negative effects on health underlies standard dietary recommendations for magnesium consumption. In Israel, these are 315 milligrams (mg) per day for adult women, 415 mg per day for adult men, and somewhere between these two for adolescents and pregnant women. Very similar recommendations are published by the national health institutions in all other high-income countries with sophisticated medical systems. Additionally, the US NIH guidelines suggest that there is no upper threshold to magnesium consumption so long as the source is natural — the kidneys get rid of any excess — though dietary supplements should not exceed 400 mg per day (NIH, 2021).

Magnesium consumption in Israel

Historically, water was an added source of magnesium in Israel. Estimations show that prior to desalination, water accounted for around 7%–17% of daily magnesium needs in Israel, ingested in the 12–16 cups of water and other beverages consumed by Israelis during the day (Koren et al., 2017; Spungen et al., 2013).⁴ As mentioned above, currently 70% of water within Israeli households is desalinated. Whatever magnesium exists in the non-desalinated water — within which there is considerable variation in magnesium levels (Koren et al., 2017; Rosen et al., 2018)⁵ — is almost wholly removed through the widespread use of domestic water filters (Brita, etc.), used by 25%–50% of the population (Spungen et al., 2013). The Ministry of Health *MABAT* nutritional surveys, include an estimation of the amount of magnesium consumed via drinking water: tap water — 32.4 mg/l, bottled water, 28 mg/l, filtered water — zero. The surveys found that 46% of the population drinks filtered water, 31% drinks tap water, and 23% drinks bottled water. Despite the widespread use of domestic water filters, the serum magnesium level of cardiac patients living in desalinated water areas was significantly lower compared to cardiac patients living in non-desalinated areas (Koren et al., 2017).

4 These estimations and others may vary depending on a variety of factors and assumptions.

5 Natural water sources vary in all types of minerals. In relation to magnesium, Koren et al. (2017) report that fresh water from the Israeli National Water Carrier (NWC) contains 20–25 mg magnesium per liter, but in the authors' sample of tap water from 24 non-desalinated locations, they found levels between 11–37.5 mg/l (mean 25.1). This difference between water in the NWC and tap water therefore reflects the addition of other water sources — local springs and groundwater — in different places. Similarly, Rosen et al. (2018) point to the “stable but very low levels of magnesium in the Dan River water of northern Israel.”

According to MABAT surveys on the health and nutrition status of individuals aged 18–64 and those aged 65 and over (Ministry of Health, 2019a, 2019b), three main patterns can be seen in terms of magnesium consumption, as shown in Table 2.

1. Magnesium deficiency — defined as consuming less than the recommended amount — can be found in all age groups and among Jews and Arabs and men and women. Pronounced deficiencies are among younger men and women (18–34). They averaged 68 mg and 60 mg less than their respective recommended amounts. This age pattern is particularly strong for Jews, where both older men and women have higher magnesium consumption than their younger counterparts. Among Arabs, in contrast, the age-pattern is not monotonous. Nor is it similar for men and women. Young Arab women, in particular, have low consumption — 96 mg less than the recommended amount.
2. Israeli Arabs aged 45–64: women and men have 51 mg and 53 mg less consumption, respectively, than the recommended amount. This is worrying since individuals in this age group are more likely to have conditions that impede the effective absorption of magnesium. (The lack of specific data on milligrams of magnesium consumed at ages 65+ means that we cannot know how much this continues into the oldest age groups. But among men in particular, the percent with magnesium deficiency rises rapidly at oldest ages).
3. Among women, the middle age group, 35–44, and among men, the 45–64 age group have the highest magnesium consumption.

Table 2. Recommended daily consumption of magnesium and deviations from those recommendations in Israel's national nutrition survey, 2014–2016, by age and subpopulation

	Recommended (mg)	Jewish (mg)	Arab (mg)	Total (mg)
Female				
18–34	315	-60	-96	-68
35–44	315	-10	-24	-13
45–64	315	-10	-51	-16
65–74	265		(53% deficient consumption)	
75–84	265		(60% deficient consumption)	
85+	265		(60% deficient consumption)	
Male				
18–34	415	-67	-33	-60
35–44	415	-25	12	-17
45–64	415	-9	-53	-16
65–74	350		(60% deficient consumption)	
75–84	350		(65% deficient consumption)	
85+	350		(80% deficient consumption)	

Note: Given that the estimates regarding deviations from the recommendations are based on magnesium levels in drinking water before desalination, the actual deviations may be even greater, especially today when desalinated water constitutes 70%–80% of total drinking water.

Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center | Data: Ages 18–64 adapted from p. 141 in Ministry of Health (2019a); ages 65+ adapted from p.171 in Ministry of Health (2019b).

In general, these patterns appear to be consistent with dietary trends. Foods rich in magnesium include green leafy vegetables, legumes, nuts and seeds, wholegrains, milk, yogurt, and some other milk products. Consumption of these items has historically been quite high in Israel. However, it has been falling for some, giving way to more low-magnesium processed foods, especially among younger cohorts. This dietary shift is also consistent with other trends. In particular, a comparison of data from MABAT 1999–2001 and MABAT 2014–2016, shows that dietary intake of potassium, found in many of the same foods as magnesium, fell by 9%, and Vitamin C intake, an indicator of fresh fruit consumption, was down by almost 50%. Note that mild increases in consumption of dietary fiber and calcium across the same period suggest that consumption of vegetables, wholegrains and dairy products did not fall. In other words, any reduction in magnesium intake does not appear to stem

solely from dietary changes, unless the magnesium content of local agricultural products is also falling. That may be the case. There is some evidence that the increasing use of (mainly recycled) desalinated water in agriculture itself reduces the magnesium content of local produce (Raveh & Ben-Gal, 2018; Yermiyahu et al., 2007).

Epidemiological data on associations between lack of magnesium in water due to desalination and health are scarce. In a large cohort study based on the Clalit Health Services database, a 6% increase in the odds of ischemic heart disease was found among the population aged 25–76 living in areas in which the water supply changed to desalinated water compared to populations that receives non-desalinated water. No difference was found in the incidence of diabetes mellitus (Shlezinger et al., 2018). A number of studies in countries in which natural differences in the concentration of magnesium in drinking water occur have been published. A meta-analysis of 10 studies involving 77,821 coronary heart disease patients found that coronary heart disease mortality was 11% lower among patients with more magnesium in their drinking water (Jiang et al., 2016). However, a more recent study found protective associations with magnesium only with incidence of acute myocardial infarction and not with stroke (Theisen et al., 2022).

Overall, therefore, the available evidence points to a reduction in average consumption of magnesium, rooted in both the increasing use of desalinated water, filtered water, shifts in diet, and potential reduction in magnesium concentrations of fresh produce. In this respect, the increasing reliance on desalinated water in Israel is exacerbating an existing problem of magnesium deficiency in the Israeli public. We assume that the reduction in magnesium consumption lies in the range of 15%–20%, that is, somewhat higher than Koren et al.'s (2017) estimation of water alone. At the recommended doses of magnesium listed in Table 2, that would be a drop of 50–80 mg/day. On this basis, the empirical estimates that we describe below focus on marginal reductions of 50 mg/day.

Estimating the effects of magnesium deficiency on health in Israel

This potentially negative consequence of desalination, in particular through magnesium deficiency, has long been recognized in Israel. Discussions about adding magnesium to desalinated drinking water in Israel began in 2004, when an advisory committee for updating drinking water regulations,

headed by Prof. Avner Adin, initiated its activities. Following the Ministry of Health's recommendation to enrich desalinated water with magnesium, the Public Health Regulations from 2013 stipulated that by September 2018, the significance and costs of adding magnesium to drinking water at a concentration of 20–30 mg/l should be examined and relevant recommendations should be submitted. A steering committee established by the Ministry of Health to examine the issue published a report in January 2021 that assessed the health costs of magnesium deficiency in drinking water, as well as the cost of adding magnesium to desalinated water. The report argued that the economic benefits of reducing morbidity and mortality from type 2 diabetes, coronary heart disease, and ischemic stroke by adding magnesium to desalinated water would outweigh the costs, and recommended adding magnesium to reach a concentration of 30 mg/l of desalinated water (Tahal Consulting Engineers, 2021).

Empirical goals

This research has two goals. Each goal builds on the literature detailed above: the recognized negative effects of magnesium deficiency on health; the falling levels of magnesium consumption in Israel; the possible role that desalinated water plays in this reduction; and the calls to add magnesium to desalinated water in order to help reverse these trends.

Our first goal is to quantify some of the health effects in terms of the extra *morbidity* arising from magnesium deficiency. We focus in particular on the effects of lower magnesium consumption on the *incidence* of type 2 diabetes (T2D), and ischemic stroke (IS). A recent comprehensive meta-analysis, detailed below, suggests that effects of magnesium deficiency are strongest on these two conditions (Zhao et al., 2020). We acknowledge the significant health literature on the effects of magnesium deficiency on other significant causes of morbidity and mortality — in Israel specifically, ischemic heart disease, atrial fibrillation, and colorectal cancer (Shlezinger et al., 2018, 2019) — but our analysis does not cover those conditions. It should therefore be seen as an underestimate of the total disease burden associated with magnesium deficiency.

Our second goal is to estimate the *direct* economic costs to the health care system associated with the added burden of T2D and IS. We intentionally ignore the *indirect* costs of that added disease burden, since that demands too many assumptions about types of care and carers, including the effects on carers' own employment, and on their mental and physical health (Arazi et al., 2023). Even with this underestimate, magnesium deficiency appears to be associated with very substantial extra health expenditures.⁶

Data

Data on the incidence of IS and T2D in Israel are taken from the Global Burden of Disease (GBD) Israel-specific files covering 2019.⁷ Initial estimates of the overall effect of a reduction in magnesium uses GBD's *age-standardized* incidence. Estimated effects on years of life lived with diabetes use *age-specific* incidence data in combination with life expectancy estimates from prospective studies in the UK — described below — and data on management of diabetes from the Ministry of Health.

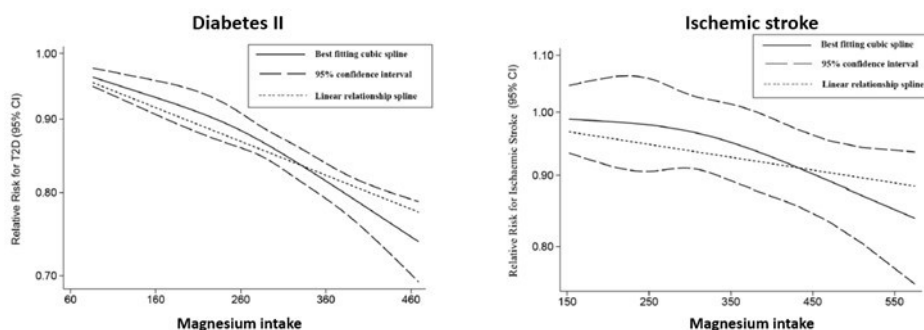
Based on the observed consumption patterns reported in Table 2, we provide a range of starting points for magnesium consumption, from 250 mg–450 mg from which we calculate the potential health effects of deficiencies in consumption. The estimates of the effects of lower magnesium consumption on IS and T2D are based on a dose-response trend from a meta-analysis of prospective cohort studies (Zhao et al., 2020).

The key trend-line that we use here to estimate the effect of magnesium consumption on the incidence of T2D and ischemic stroke is represented by Zhao et al.'s (2020) “best fitting cubic spline,” reproduced in Figure 1.

6 We also choose not to quantify the effects of magnesium deficiency on mortality since that also demands many more assumptions. For example, the speed with which morbidity related to magnesium deficiency leads to death — say, through badly managed T2D or a recurrent stroke — is influenced by medical systems' coverage and available medical personnel's skill levels.

7 Data are from IHME, 2023.

Figure 1. Association of magnesium intake with incidence of type-2 diabetes and ischemic stroke



Source: Zhao et al., 2020, p. 11 (part of Figure 3)

Zhao et al.'s estimates imply that the effects of a reduction in magnesium consumption on the incidence of both T2D and IS are much stronger at higher levels of magnesium consumption, that is, closer to the recommended daily dose. The gradient is particularly sharp for T2D. The risk of T2D for people with the highest magnesium intake was found to be 23% lower than for the people with the lowest magnesium consumption. For ischemic stroke the benefit of highest magnesium intake was a 10% reduction in the risk ratio (RR⁸) compared to the lowest intake. These sharper gradients closer to the daily recommended dose make some intuitive sense given the wide range of regulatory roles that magnesium plays in the body, detailed above.

How many cases would be avoided given a 50 mg increase in magnesium consumption?

Using the relative risk ratios in Figure 1, Table 3 below reports the implied number of new cases of T2D or IS that would be avoided if consumption of magnesium was to rise by 50 mg from four different thresholds along the “best fitting cubic spline” in Zhao et al. (2020): from 250 mg to 300 mg, 300 mg

8 The risk ratio or relative risk (RR) measures the association between an exposure and an outcome. It is a probability of the risk of the outcome in the exposed vs. the unexposed population.

to 350 mg, 350 mg to 400 mg, and 400 mg to 450 mg. These are realistic thresholds given the actual levels of magnesium consumption reported in the 2014–2016 national nutrition survey, shown in Table 2 above.

Note these estimates of number of cases avoided are based on age-standardized incidence rates applied to Israel’s mid-2023 population of 9.7 million.

Table 3a. Risk ratio (RR) of Zhao et al.’s best fitting estimate and the implied annual number of new T2D cases avoided in Israel by 50 mg increase in magnesium intake

Increasing natural intake from:	RR (Zhao et al., 2020)	Diabetes type II
250 mg – 300 mg	0.966	853
300 mg – 350 mg	0.952	1,178
350 mg – 400 mg	0.950	1,237
400 mg – 450 mg	0.934	1,627

Table 3b. Risk ratio (RR) of Zhao et al.’s best fitting estimate and the implied annual number of new IS cases avoided in Israel by 50 mg increase in magnesium intake

Increasing natural intake from:	RR (Zhao et al., 2020)	Ischemic stroke
250 mg – 300 mg	0.995	23
300 mg – 350 mg	0.989	46
350 mg – 400 mg	0.969	139
400 mg – 450 mg	0.968	144

Note: Numbers based on mid-2023 population data.

Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center | Data: IHME, 2023; Zhao et al., 2020

Two main findings emerge from this initial calculation. First, the effects on the incidence of T2D in Israel are much greater than the effects on IS. This is not surprising. Not only is the prevalence of T2D much greater than IS in general, but among high-income countries, Israel’s T2D prevalence is known to be high, even as management of T2D has also substantially improved (Ministry of Health, 2023), while its incidence of IS is near the bottom. An equivalent percentage increase in the incidence of both will therefore lead to a much larger absolute increase in the number of people with T2D than number who suffer from IS.

This strong effect of magnesium deficiency on T2D is worrying. According to both the WHO global report on diabetes (WHO, 2016) and the latest version (10th edition) of the International Diabetes Federation Atlas (IDA), the Eastern Mediterranean is now the most affected region in the world in terms of overall diabetes prevalence and its impact on mortality. In Israel, in particular, 8.5% of Israeli adults in the 20–79 age group have diabetes. In the European region — the IDA categorizes Israel and Turkey as “European” — only countries in the Balkans (Albania, Bosnia and Herzegovina, Serbia, Montenegro), Iberian Peninsula (Andorra, Portugal, Spain), and Eastern Mediterranean (Cyprus, Turkey) have an equivalent or higher diabetes prevalence (11 out of 59 countries). Importantly, the risk of diabetes in Israel is higher in population groups characterized by low SES (Ministry of Health, 2021). Baseline dietary magnesium consumption among these populations, as well as the rate of consumption of dietary supplements, has been found to be lower than among high SES populations (Shahar et al., 2005; Tahal Consulting Engineers, 2021). Therefore, the absence of magnesium in drinking water is likely increasing SES inequalities in morbidity.

The second key finding to emerge from this analysis is related to the sharper gradient in the risk-ratio at higher levels of magnesium consumption, especially in relation to T2D, discussed above in relation to Figure 1. In terms of cost, as we now show, this is the more important effect.

Cost of those extra cases

The scholarly literature on the cost of disease incidence to health systems is highly developed and quite technical, as evident in the recent proposed list of methodological criteria issued by the British Medical Journal for economic submissions (Wang et al., 2018). Given the greater impact of magnesium deficiency on T2D, and the fact that T2D is considered the largest driver of overall healthcare costs and reduced life expectancy in Europe (Khan et al., 2020; Soares Andrade et al., 2023), we first focus on T2D. Our estimates of the cost of magnesium deficiency on ischemic strokes use a different methodology, so are discussed separately. It is important to emphasize that our approach is very conservative, meaning our cost estimates are biased downwards. We will address this in detail in the discussion section.

Type II Diabetes

We follow existing standards in terms of differentiating type-1 from type-2 diabetes, and differentiating *direct* from *indirect* costs. In terms of broad categories, the direct costs of T2D include in- and out-patient care, medication and assorted *other* costs. In- and out-patient care includes both the direct treatment of diabetes itself and the treatment of other conditions arising directly from diabetes. These include diabetic retinopathy and blindness, foot disease (with inadequate care this can lead to amputation), various types of cardiovascular disease, renal disease, erectile dysfunction, and an array of neurological complaints (Kanavos et al., 2012; Stegbauer et al., 2020). Consistent with this approach, medication-related direct costs include drugs, like insulin, that directly target diabetes, and also medication directed at complications arising from diabetes, such as cardiovascular medication, cholesterol lowering, anti-platelet, psychotropic drugs, antacids, antibiotics, immune-suppressants, and anti-anemic drugs. Finally, the “Other” costs category refers primarily to medical devices or equipment like injection devices, self-blood glucose monitoring equipment, insulin pumps, and oxygen-therapy (Kanavos et al., 2012).

Indirect costs of T2D include the reduced or total inability to work, associated costs to caregivers (who may need to reduce working time in order to look after loved ones), and, at the national level, additional welfare payments associated with disability allowances and similar benefits. In other words, the indirect costs arise from reduced productivity while people are still in the labor force, early retirement, and increased *non-medical* public transfers. As mentioned above, because of the difficulty of assessing indirect costs, we ignore them here.

Methodology

Absent data on the direct cost of each of the health inputs listed in the preceding paragraphs, we estimate the added financial burden associated with magnesium deficiency using an indirect method. We begin by calculating the *extra person-years* lived in the population by people with T2D, where that *extra* can be ascribed to magnesium deficiency.

We assume a population with N individuals who can be bifurcated into N^A individuals without T2D and N^B individuals with T2D, $N^A + N^B = N$. Note that N^B includes all those who have become infected with T2D who are still alive.

In other words, N^B is a function of two factors: the incidence of T2D in past years and survival times.⁹ Each group can be further broken down by age, with N_i^j denoting the number of people of type j (A or B) of age i , $i \in [0, \infty]$.

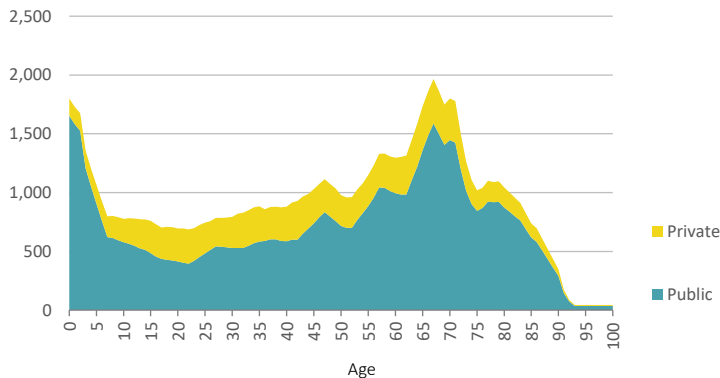
In any given year, the country's total medical costs (TMC) can be drawn directly from an analysis of Israel's National Transfer Accounts (NTA).¹⁰ In 2018, Israel's TMC was NIS 94.5 billion. The NTA also gives estimates of TMC by age, TMC_i — shown in Figure 2 for 2018 — from both public and private expenditures. Dividing these aggregate expenditures by the population at each age, N_i , gives a per capita estimate of *aggregate* health expenditures for every age. We denote by C_i^j the average per capita medical cost for a person of type j of age i , and by C_i^j the average per capita cost for all those of type j (A or B). Note that both N_i^j and C_i^j vary with age, the former because of fluctuations in age structure, and the latter due to rising health spending with age — formalized in the capitation formula in Israel's public healthcare system. TMC , then can be written as:

$$TMC = \sum_{i=0}^{\infty} (N_i^A \cdot C_i^A + N_i^B \cdot C_i^B)$$

9 We ignore international migration here. This likely, though mildly, underestimates diabetes-related costs since the “healthy migrant” effect suggests that non-migrants will have higher diabetes prevalence than migrants — the former is more likely to include people diagnosed with diabetes who, assuming access to medical care, are less likely to migrate.

10 The National Transfer Accounts (NTA) project integrates countries' demographic and economic characteristics, and documents all national financial flows and transfers, with a particular focus on public and private expenditures on health and education. NTA data are available for around 80 countries (Weinreb et al. [forthcoming]).

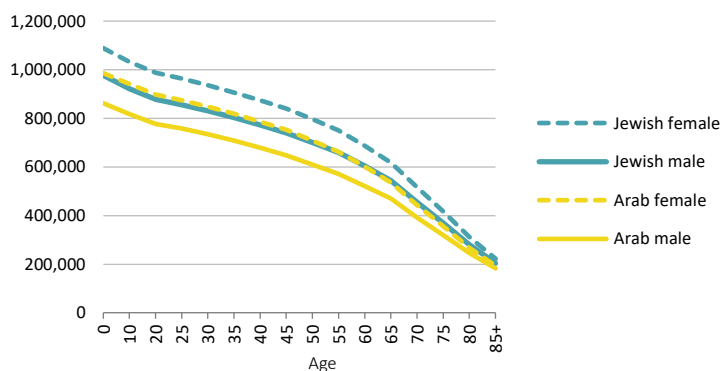
Figure 2. Aggregate health expenditures in Israel, 2018, by age and source
NIS million



Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center | Data: Weinreb, et al. (forthcoming)

Applying these expenditures across the life-course allows us to estimate the total per capita lifetime spending for a person subject to these age-specific expenditures from birth until death. Figure 3 presents these expenditures, by subpopulation and sex. The key point to take away from Figure 3 is that more than 60% of health expenditures occur above age 60, that is, in the last quarter of people's lives. Therefore, anything that increases per capita expenditures below age 60 is going to have a substantial effect on total health spending.

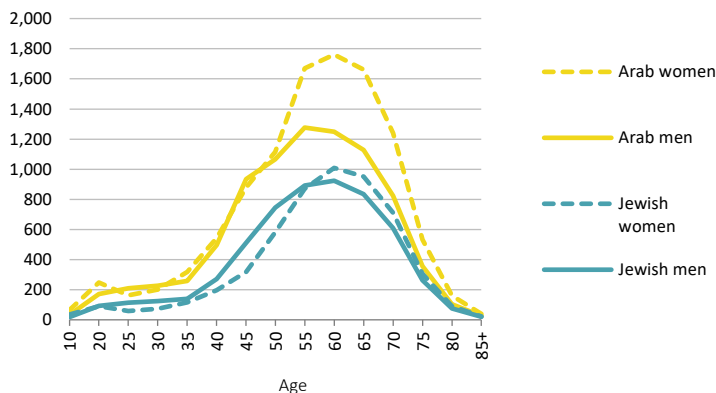
Figure 3. Total remaining medical expenditures, by age, sex, and ethnicity
NIS



Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center | Data: Weinreb, et al. (forthcoming)

To distinguish between C^A and C^B , we draw on prior analyses across developed countries with universal health care systems and similar life expectancy to Israel. These have yielded a relatively small range of estimates for the per capita health expenses of people with T2D (C^B) relative to people without (C^A). Specifically, studies in France, Germany, and Israel, suggest that people with T2D had 1.7 and 1.8-fold higher per capita expenses (Balicer et al., 2018; Charbonnel et al., 2018; Jacobs et al., 2017). An analysis of UK data that more carefully distinguished age-related increases in medical costs from those associated with T2D put the ratio at 2 to 3 times more than age-matched and sex-matched patients without diabetes (Stedman et al. 2020), which is consistent with other international comparisons, like those published by the International Diabetes Federation (IDF, 2009, pp. 36–37). In our calculations, we set the range of per capita health costs for a person with T2D to 1.7 to 2.7 times the per capita health costs without T2D, calibrating it to the absolute level of healthcare spending, TMC, observed in Israel's National Accounts in 2018 (i.e., NIS 94.5 billion). Note, too, that using a ratio of T2D to non-T2D per capita costs has a distinct advantage over an estimate of actual costs since we can assume that any large-scale system-wide reductions in medical costs — allowing for more efficient provision of health services — should equally apply to both subpopulations.

As noted above, we use incidence data from the Global Burden of Disease (GBD) Israel-specific files covering 2019. These provide distinct incidence profiles for Israeli men and women. We combine these with age-specific estimates of incidence for Jews and Arabs presented in Jaffe et al. (2017), smoothing the broader age-categories in the latter along the lines of the national estimates. This procedure yields the age-specific incidence rates (annual number of new cases per 100,000) by ethnicity and sex shown in Figure 4. It is worth noting that the T2D age-profile is unlike that of other major chronic conditions in that the incidence rate rises then falls. In contrast, the incidence of ischemic stroke (IS), as we shall show below, continues to rise with age deep into people's 80s. That is also the standard pattern for heart disease and most types of cancer (Driver et al., 2008; Frank, 2007). This difference between the age-specific incidence patterns for diabetes and IS has significant implications for health expenditures.

Figure 4. Age-specific incidence of T2D in 2019, by sex and ethnicity

Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center | Data: Jaffe et al., 2017, calibrated to higher-resolution age-specific incidence in the Global Burden of Disease Project

Survival estimates for T2D — the second factor contributing to N^B — are adapted from Leal et al. (2009). Using data from the United Kingdom Prospective Diabetes Study (UKPDS), they estimate life expectancy at ages 55, 65, and 75, and compare it to the life expectancy of T2D patients diagnosed 5 years earlier across low and high-risk health characteristics, and to the general population. In both cases, T2D reduces life expectancy. As shown in Table 4, for those with low-risk characteristics — implying well-managed T2D — a T2D diagnosis implied a 3.6 years reduction in life expectancy at age 55 (21.1 years instead of 24.7). At age 65, T2D led to a 1.7 years reduction in life expectancy, and at age 75 it led to a 0.4 years reduction. For those with high-risk characteristics — implying badly-managed T2D — the reductions in life expectancy at each age were much larger, falling by 11.5, 6.9 and 5.7 years at ages 55, 65 and 75 (compared to life expectancy free of T2D), respectively.

Table 4. Estimated life expectancy at ages 55, 65, and 75, in the general population and among T2D patients diagnosed 5 years previously, by general health characteristics

Male life expectancy at age:	55	65	75
e_x (UK general male population)	24.7	16.6	10.0
Diagnosed type 2 five years earlier			
— Low risk characteristics (years)	21.1	14.9	9.6
— High risk characteristics (years)	13.2	8.0	4.3

e_x — expectation of life at age x

Low risk: Systolic blood pressure (SBP) of 120 mm Hg, total HDL:cholesterol ratio of 4, and HbA1c of 6%.
High risk: SBP of 180 mm Hg, total HDL:cholesterol ratio of 8, and HbA1c of 10%.

Note: We illustrate the difference in life expectancy between well managed and poorly managed T2D using UK male life expectancy figures. The proportionate effects are the same for women.

Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center | Data: Leal et al., 2009

Lifetime cost of a single year cohort of T2D incidence

Table 2 presented estimates of the annual number of new cases that would be avoided in Israel by a 50 mg increase in magnesium intake. The long survival of people who can successfully manage T2D — shown in Table 4 — points to the main source of diabetes' direct contribution to overall health costs: in a successful public health system, like Israel's, a large majority of people with T2D will live for many years, but the annual cost of their medical care is significantly higher than that of their non-T2D counterparts.

We show this here by estimating the anticipated savings associated with raising magnesium consumption by 50 mg for a single year and preventing the estimated new cases in Table 2. Specifically, we:

1. Distribute the 24,500 new T2D cases in 2019 in accordance with the estimated age-specific rates, by sex and ethnicity, presented in Figure 4;
2. Estimate the expected person-years (i.e., life expectancy) lived by a non-T2D person at each age, by sex and ethnicity, using the CBS official life tables for the 2015–2019 period;
3. Estimate the expected person-years (i.e., life expectancy) lived by each new T2D case by applying the percent reduction in life expectancy implied in Table 4 under four conditions: that the percent managing T2D well is 80%, 85%, 90%, and 95%;¹¹ and

11 The percent of T2D managed well means that these diabetic patients have low risk characteristics and therefore have a higher life expectancy, as shown in Table 4. These patients are characterized by: Systolic blood pressure (SBP) of 120 mm Hg, total HDL:cholesterol ratio of 4, and HbA1c of 6%.

4. Multiply these estimated number of person-years lived by all 24,500 new T2D cases in 2019 by the per capita health expenditures of a T2D person (C_i^B) at each age, under two conditions: that the ratios of per capita T2D medical costs (C^B) vs non-diabetes costs (C^A) is 1.7 or 2.7.

These four steps give us the total cost associated with the *lifetime treatment* of all 24,500 new T2D cases in 2019 (in constant 2018 shekels), given the spending ratio is somewhere between 1.7–2.7.

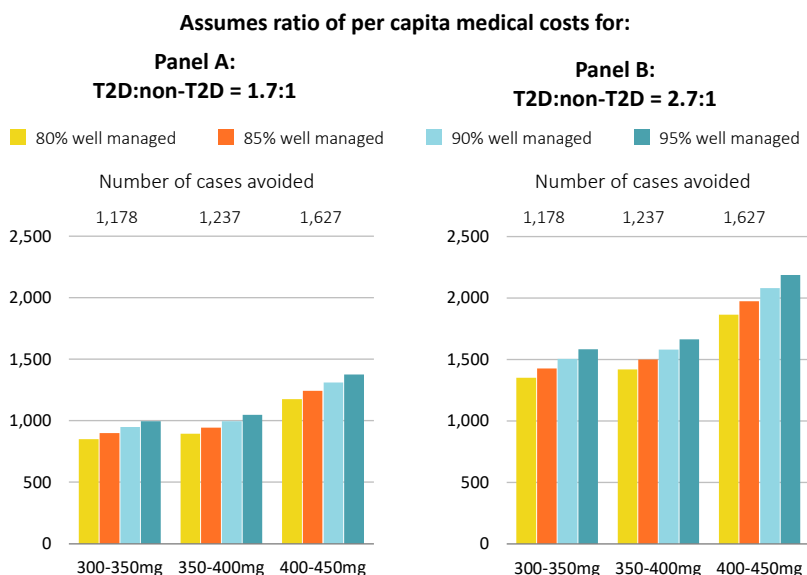
To look at the savings, we then replicate the calculation across the three steps from three different starting points for baseline magnesium consumption: 300, 350, and 400. In other words, we reduce the total number of new cases in step 1 in accordance with the calculations presented in the final column of Table 3a.

Results are presented in Figure 5. They point to the implied *lifetime savings* associated with preventing some share of new T2D cases experienced *in a single year, 2019*, from happening by raising magnesium consumption by 50 mg. By lifetime savings we refer to direct medical costs from the time of diagnosis to death.

The estimates in Panel A assume that direct medical costs for T2D individuals are 1.7 times as large per capita as those of non-T2D individuals. Panel B estimates assume that the ratio is 2.7:1. In each panel, there are three clusters of estimates, each representing the number of new T2D cases avoided by adding 50 mg of magnesium. The specific number of cases avoided is marked at the top of each set of columns, with the specific range of magnesium — baseline + 50 mg — noted at the bottom. As mentioned above, these correspond to the best-fitting spline reported in Zhao et al. (2020).

At a minimum — assuming that magnesium consumption can be raised from 300 mg to 350 mg per day, that 80% of the 23,100 new cases (24,278 minus the 1,178 avoided cases) were well-managed, and that the ratio of per capita costs was 1.7:1 for people with T2D versus people without — results show that the 1,178 avoided cases would save the Israeli medical system NIS 850 million across the expected lifetime of that cohort. Savings increase as the number of cases avoided goes up, and as the percentage managing T2D well goes up (pushing up survival rates among people with T2D): rising to NIS 997 million where 1,627 cases were avoided and 95% were well-managed. As shown in the right-hand panel, savings jump even more dramatically as the ratio of per capita costs for people with T2D versus people without increases.

Figure 5. Millions of shekels saved to lifetime direct medical costs by raising magnesium consumption by 50 mg for the 2019 levels of incidence
NIS million



Note: The costs are presented by the ratio of T2D per capita medical costs to non-T2D medical costs, number of cases avoided, and percent of T2D patients managing their condition well.

Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center | Data: IHME, 2023; Leal et al., 2009; Weinreb et al. (forthcoming); Zhao et al., 2020

These lifetime savings can be broken down into approximate single-year estimates. These are shown in Table 5. Assuming that 90% of the 1,178 avoided cases in the first set of columns in Figure 5 are well-managed, and that the ratio of per capita costs is 1.7:1 for people with T2D versus people without, then each of those 1,178 avoided cases would save an average of NIS 805,000 across their lifetime, that is, from the point of diagnosis. To clarify: this is the extra cost associated with T2D over standard per person health costs. Assuming a mean life expectancy of 15 years after diagnosis (mean age of 60 for Jews, 55 for Arabs), that translates into an additional NIS 53,653 per T2D patient per year. This is the value shown in the table (second row, left-

hand column).¹² Overall, for all the cases that were prevented, approximately NIS 63 million per year would have been saved.

Table 5. Additional costs per year per T2D patient, assuming 15 years life expectancy from diagnosis

NIS, 2018 prices

	Ratio of T2D:non-T2D patient costs	
	1.7:1	2.7:1
95% well managed	56,418	89,605
90% well managed	53,653	85,213
85% well managed	50,887	80,821
80% well managed	48,122	76,429

Note: The estimates are based on data presented in prior tables and figures.

Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center

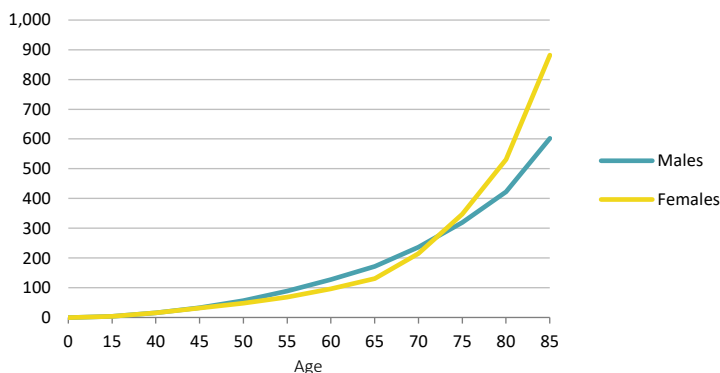
If all conditions remained the same but the ratio of per capita costs was 2.7:1 for people with T2D versus people without, savings would amount to NIS 73.3 million per year, which is around NIS 85,213 per patient per year.¹³

Costs of extra incidence for ischemic stroke

We use a different method to estimate the costs of added cases of ischemic stroke (IS) arising from magnesium deficiency. The main reason for this difference is that, as shown in Figure 5, and unlike T2D, the incidence of stroke rises with age, and at an increasing rate. This means that although people can experience ischemic strokes at any age, including childhood (deVeber et al., 2017; Gao et al., 2023; Putaala, 2016), the mean age at onset of a first stroke is much older than diabetes: 71 years in Israel (Tanne et al., 2006).

12 For brevity we only present values based on magnesium consumption rising from 300 mg to 350 mg per day. The marginal per patient-year cost is very similar going from magnesium consumption of 350–400 mg or 400–450 mg.

13 Table 5 suggests that as the share of T2D patients managing their condition well falls, these extra costs to the medical system also fall. This is an artifact of assuming life expectancy of 15 years from the incidence of the disease onwards. It suggests that *savings* to the system from these patients' lower survival rates more than offsets any increase in spending while they are still alive.

Figure 6. Incidence of ischemic stroke in Israel in 2019, by age and sex

Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center | Data: IHME, 2023

This high median age in itself reduces survival time much more than for diabetes. Estimates from the Erlangen Stroke Project in Germany, a prospective, population-based stroke register, point to 5-year survival probabilities of 50.4% (95% CI, 47.9–53.1) in women and 59.2% (95% CI, 56.4–62.0) in men (Rücker et al., 2020). Estimates from other settings point to similar survival rates, though with the expected age-gradient that younger survive longer (Rosamond et al., 2008). According to Global Health Data Exchange, both stroke incidence and mortality have been falling relatively consistently in Israel for 30 years, as the quality of care has been improving (Ram et al., 2019). This is consistent with improving survival rates observed in other high-income countries, as both case fatality rates at the first stroke and stroke recurrence rates fall (Rücker et al., 2020; Wafa et al., 2020) but estimates by aetiological subtypes are limited. This study estimates time trends in mortality and functional dependence by ischemic stroke (IS).

The much more limited lifespan after a stroke, relative to diabetes, mostly stemming from stroke's high median age at incidence, reduces the importance of considering lifespan effects on cost. To estimate the anticipated cost savings associated with raising magnesium consumption, we build directly on existing estimates of stroke-related costs in Israel and elsewhere.

In their review of the economic cost of strokes across 31 countries, Luengo-Fernandez et al. (2020) list the total direct medical cost of all types of strokes in Israel in 2017 — including medical care in the primary, outpatient, emergency, and hospital settings, and all medication — at 0.86% of total healthcare expenditures.¹⁴ Assuming that the share of total healthcare expenditures on strokes remained 0.86% in 2018, this amounts to NIS 819.03 million.

Our focus here is on IS, which differs from other types of stroke both in terms of incidence and direct medical costs. Specifically, IS comprises more than 80% of strokes in Israel: 81% in Rozenhul-Sorokin et al. (1996), though in a sample of under 50s; 89% strokes in Tanne et al. (2006). These distributions are similar to estimates elsewhere — 87% in the US (according to U. S. Centers for Disease Control and Prevention).

IS is also less costly than other types of strokes. A careful decomposition of direct medical costs in Singapore, for example, showed that total medical costs associated with subarachnoid hemorrhage (SAH) and intracerebral hemorrhage (ICH) were, respectively, 2.5 times and 1.7 times as much as IS (Ng et al., 2015).

Combining these differences in both the incidence of different types of stroke and the associated medical costs implies that total medical expenses associated with ischemic stroke in Israel was around NIS 743.8 million (78.1% of the total spent on strokes). By applying the reduction in risk ratio estimated in Zhao et al. (2020) and shown in the second column of Table 6, we can estimate the total savings to direct medical expenditures on IS.

These estimates are shown in the final column of Table 6. They imply that a 50 mg increase in magnesium intake would, depending on the baseline, save a relatively modest NIS 3.7–23.8 million per year (given 2018 health expenditures and costs). This is a fraction of the savings associated with T2D, not surprising given the combination of a relatively shallow reduction in the RR of IS relative to T2D, and the relatively low incidence of stroke in Israel in general. However, this is direct medical costs alone. It does not include any of the indirect costs arising from longer term care of chronic stroke patients, which is at least as costly a stage. In the UK, Saka et al. (2009) estimates those indirect costs, including informal care, account for 51% of total costs associated with strokes.

14 This is much lower than the European average (1.65%), despite relatively low public healthcare spending in general in Israel. It is especially lower than in the UK, where a detailed disaggregation placed the annual direct cost of stroke at approximately £4 billion, accounting for 5.5% of the UK's total expenditure on health care (Saka et al., 2009).

Table 6. Implied reduction in annual expenditures on direct treatment of IS by 50 mg increase in mg intake**NIS, 2018 prices**

Increasing natural intake from:	Reduction based on Zhao et al. (2020)	Implied savings to health expenditures
250 mg – 300 mg	0.995	3,719,000
300 mg – 350 mg	0.989	8,181,800
350 mg – 400 mg	0.979	15,619,800
400 mg – 450 mg	0.968	23,801,600

Note: The estimates are based on data presented in prior tables and figures.

Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center

Effects of population growth on estimated savings

The potential savings estimated thus far are based on 2019 incidence rates applied to Israel's 2023 population. Assuming constant age-specific incidence rates, these savings are likely to increase substantially over the next two decades, since population growth, in particular higher-than-average age-specific patterns of growth at peak ages of T2D and IS incidence, will drive up the absolute number of new cases of both T2D and IS.

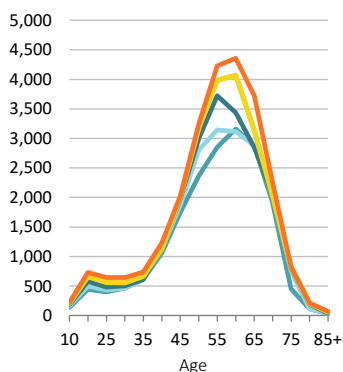
Here we apply the same 2019 age-specific incidence data used thus far to CBS population projections. This gives us the projected number of new cases of T2D in five-year intervals from 2020–2040, shown in Figure 7. For ease, we combine males and females.

The most rapid rates of increase in new T2D cases in the Jewish population will occur over the 2025–2035 period. That is when the larger cohorts currently in their early to late 40s will start to reach peak T2D incidence ages. Notably, the number of new T2D cases in the 55–64 age group will increase by around 3.0% per year in the 2028–2032 period. Subsequent aging of smaller cohorts into this age group will then reduce those growth rates to the more standard range of 1.0–2.0% per year. In total, the average rate of growth in new T2D cases in 2020–2040 will be 1.52% per year across the Jewish population as a whole.

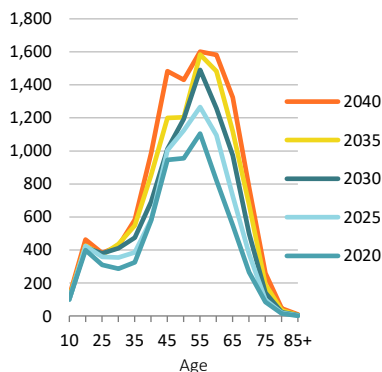
Figure 7. Projected number of new cases of type 2 diabetes up to 2040, by age and subpopulation

New cases per year

Jews/Others



Arabs



Note: The estimates combine IHME data on incidence with CBS population projections. Projections assume constant 2019 age-specific incidence rates.

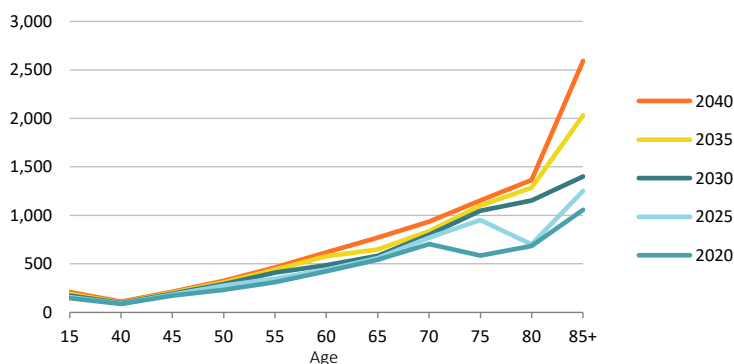
Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center

Growth in the absolute number of new T2D cases in the Arab population will be much higher, driven by a combination of a more regular age structure above age 20 and particularly rapid increases in the number of cases below age 50 as the large cohorts currently aged 20–29 move into older age groups with higher incidence rates. That will pull up the average rate of increase across all ages. If current age-specific T2D incidence rates in Israel's Arab population remain constant, the absolute number of new T2D cases in the Arab population will rise by at least 2.8% per year up to 2028 and at least 2.5% per year until 2034.

Anticipated growth in the absolute number of IS cases outpaces those of T2D, as shown in Figure 8. Overall, IS will grow by around 16% every 5 years until 2035 (annualized 2.3% per year), and then by 13% up to 2040. However, that growth will be particularly high at older ages given the much larger cohort of people currently in their early 70s, relative to those in their late 70s. Assuming constant age-specific incidence rates, we will therefore see very rapid increases in the absolute number of new IS cases in the age 80–84 group between 2025–

2030 (10.0% per year), and then in the 85+ group from 2030–2035 (7.4% per year). As mentioned earlier, chances of recovery at these ages are the lowest and costs of care higher.

Figure 8. Projected number of new cases of ischemic stroke up to 2040, by age



Note: The estimates combine IHME data on incidence with CBS population projections. Projections assume constant 2019 age-specific incidence rates.

Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center

To estimate the effects of this growth on estimated savings in health expenditures, we multiply the projected number of new cases in each year up to 2040 by the estimates of per T2D patient savings shown in Table 5 and total savings of IS shown in Table 6.

The product of these calculations is presented in Table 7. Applying the 2018 incidence and costs of IS and T2D (constant 2018 shekels) to the 2025 population implies that with 90% of T2D managing their condition effectively, annual savings to the medical system will range from around NIS 83–189 million, depending on the baseline level of magnesium consumption and extra cost of treating T2D patients. By 2030, the same range will be NIS 91–209 million, and by 2040, it will be NIS 111–254 million. Annual savings take into account both the number of new cases averted each year by consuming an additional 50 mg of magnesium per day, as well as the gradual aging and mortality of earlier cohorts.

Table 7. Annual expected direct medical expenses saved as a result of avoided incidence of type 2 diabetes and ischemic stroke following a 50 mg increase in magnesium consumption

NIS million, 2018 prices

	2025	2030	2035	2040
Assuming ratio of per capita medical costs for T2D:non-T2D = 1.7:1				
300 mg – 350 mg	82.79	91.37	100.81	110.68
350 mg – 400 mg	95.50	105.87	117.41	129.31
400 mg – 450 mg	129.53	143.81	159.73	176.11
Assuming ratio of per capita medical costs for T2D:non-T2D = 2.7:1				
300 mg – 350 mg	125.60	138.29	152.18	166.78
350 mg – 400 mg	140.44	155.12	171.32	188.20
400 mg – 450 mg	188.61	208.55	230.61	253.52

Notes: Estimates assume 90% of T2D is managed well. The estimates are based on data presented in prior tables and figures.

Source: Sadeh, Grotto, Davidovitch, and Weinreb, Taub Center

Discussion

Given current incidence levels and population size, the minimum savings in direct medical costs of treating T2D and IS that would stem from a 50 mg per day increase in magnesium consumption would be around NIS 83 million per year (2025 population figures with 2018 prices). That is the amount saved by preventing a small share of new cases of T2D and IS in a single year.

These estimated savings would be greater as the baseline consumption of magnesium increases, as success in managing T2D increases, and as the ratio of per capita costs for T2D patients to non-T2D patients increases. For example, a 50 mg increase in consumption on top of a baseline of 350 mg daily, where 90% of T2D patients manage their condition well, and there is a 2.7:1 ratio of per capita costs for people with T2D relative to people without T2D, would save around NIS 140 million per year.

We emphasize again that these are very conservative assessments, pointing to the absolute minimal cost of magnesium deficiency. We are intentionally biasing our estimates downward direction in six ways:

1. Over multiple years, the number of people saved from T2D or IS would rise cumulatively from one year to the next. In this regard, the total lifetime costs associated with cases avoided in a single year — seen in Figure 5, since it was possible to estimate this in relation to T2D — is a better measure. It points to savings in the hundreds of millions of shekels per year.¹⁵
2. Our estimates ignore the substantial array of indirect costs. Including them would roughly *double* these estimates. Our estimates also ignore other types of costs that are also not included in standard models of indirect costs, notably the emotional burden on close family members and non-familial members of a support network.
3. The incidence of T2D in Israel is increasing at younger ages. Alongside effective management of T2D, that will increase person-years lived with T2D across the life course and, through that, add to the total medical (and indirect) costs associated with T2D.
4. Our estimates ignore the multiplicative interaction between T2D and IS. Specifically, a recent meta-analysis that summarizes the shared biological mechanisms between T2D and IS argues that T2D is not only a risk factor for stroke. Rather, “cerebrovascular complications make diabetic patients 2–6 times more susceptible to a stroke event and this risk is magnified in younger individuals” (Maida et al., 2022). Consistent with our interest in generating a more conservative estimate, we hold to a simpler assumption here: that comorbidity has zero net marginal impact on the medical costs of magnesium deficiency. Future research can provide more robust guidance on this question.
5. We have only focused on the effects of magnesium deficiency on T2D and IS. Other medical conditions have also been causally linked to magnesium deficiency, in Israel in particular. These include ischemic heart disease, myocardial infarction, and colorectal cancer (Shlezinger et al., 2018, 2019) that would raise direct medical costs even further.
6. Our estimates are presented in constant 2018 NIS.

15 Some of these saved cases would presumably move into the T2D or IS column later in life. So in terms of lifetime savings the true estimate is somewhere between the single-year and lifetime estimate.

As discussed in the introduction, the elimination of a natural source of dietary magnesium as a result of water desalination is a health risk that has been extensively discussed by the Ministry of Health, but is yet to be resolved. A recent report of the Ministry of Health (Tahal Consulting Engineers, 2021) discusses adding magnesium to desalinated water to a level of 20–30 mg/l, however, it seems this technology is only in its initial phases of implementation. In Saudi Arabia, which produced 2.1 billion cubic meters of desalinated water in 2020, magnesium is added to some of the desalinated water, delivering magnesium-enriched water (about 15 mg/l) to a population of about 1.3 million (Fellows et al., 2023). Magnesium is also added to desalinated water in Cyprus, to a level of 10 mg/l, with the aim to stabilize the water (Marangou & Savvides, 2001). The extent of desalination is expected to rise in the coming years and the environmental and health challenges accompanying this technology will rise with it (Jones et al., 2019).

Conclusion

Israel's rapid transition to large-scale desalination is a technological triumph. It has allowed Israeli society to breakthrough a significant environmental constraint that once threatened the long-term sustainability of a large population with the tastes — and water consumption — of typical wealthy countries.

The demineralization of seawater that has made this triumph possible has some undesirable medical consequences. Here we have focused on two arising from magnesium deficiency. Others may arise from deficiencies in iodine, calcium carbonate (added to desalinated water in Israel), or other minerals that are removed during desalination. In either case, this problem is potentially fixable. According to costs quoted in a report issued by the Ministry of Health, the annual cost of adding magnesium to water using the cheapest technology is expected to be around NIS 37 million for supplying water to approximately 10 million people, whereas with a more expensive yet technically simpler technology, the cost is expected to reach around NIS 270 million per year (Tahal Engineers Consultants, 2021).

There are some other barriers to implementing this change that also need to be addressed. Even as the World Health Organization's Guidelines for Drinking water states that water is an important source of magnesium and, therefore, magnesium should be added to water, especially in populations with low

magnesium consumption, it falls short of recommending guidelines regarding the desired amount of magnesium in drinking water (WHO, 2022).

The effect of domestic water filters, widely used in Israel (Spungen et al., 2013), should be further investigated and addressed. Adding magnesium to desalinated water will contribute less to people's magnesium intake where they use filters (it will still add some given use in cooking and probably increased magnesium levels in fresh produce). Luckily, since domestic water filters are used less by populations of lower socio-economic status, adding magnesium to drinking water universally will have a higher effect on these populations. This is the core target population for such a step given lower consumption of dietary supplements in low SES populations than in their higher SES counterparts (Tahal Consulting Engineers, 2021).¹⁶

Israel's unusual demography makes it even more important that the problem of low magnesium consumption is addressed now. The estimates provided here are direct medical costs alone given *current* population size. Yet among developed countries, Israel's young age structure is unique. We have documented how rapid population growth over the next 20 years, heightened in age groups most susceptible to T2D and IS, will lead to rapid increases in the absolute number of new cases. This underscores the urgency of taking quick steps to prevent as many new cases of T2D and IS as possible. Increasing magnesium consumption should be one of those steps.

16 The use of domestic water filters in Israel needs to be studied separately. Water quality in Israel is high. For most of the population, they may be unnecessary (Rosen et al., 2018).

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