High hardness water consumption and the incidence of myocardial infarction: Systematic review of the literature

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Abstract

This systematic review evaluates and synthesizes existing scientific evidence on the impact of high hardness water consumption on the incidence of myocardial infarction, with a focus on dissolved minerals, such as calcium and magnesium. Through the PICO methodology and following the PRISMA 2020 guideline, six main studies were selected from a total of 202 articles. The results show a significant protective effect of water hardness, mainly attributable to the presence of magnesium and calcium, essential elements for cardiovascular health. Five out of six studies showed an inverse correlation between water hardness and risk of myocardial infarction. Despite the promising results, the study has some limitations, including the restriction to three main databases and the exclusion of studies in languages other than English, which may have omitted relevant data. In addition, the small size of some of the populations analyzed may limit the generalizability of the results.

Introduction

Water is an essential component of the human diet, essential for maintaining vital functions such as regulating body temperature, transporting nutrients, and eliminating metabolic wastes. Although water is universally recognized as essential for life, attention to its quality and mineral composition has increased in recent decades, especially regarding the impact of dissolved minerals on human health[1-4]. The quality of water is determined not only by its purity, but mainly by the presence of dissolved minerals, obtained mainly through diet, or even through water consumption, which can contribute significantly to the daily intake of some of them, especially in areas where the concentration of these trace elements is particularly significant in water resources. A topic that has a high resonance in the scientific literature today is the relationship between the amount of Total Dissolved Solids (TDS) in drinking water and their possible long-term health effects and, more specifically, the influence of alkaline earth ions such as calcium and magnesium, characteristic elements of high hardness drinking water, on human well-being. The health significance of water hardness was first highlighted in the late 1950s by epidemiological studies that found an inverse correlation between cardiovascular diseases (CVDs) and drinking water hardness. More than a hundred studies conducted worldwide over the next two decades found a significant incidence of CVDs in populations served by water with reduced calcium and magnesium contents[5-11]. Numerous research studies conducted subsequently, based on the latest epidemiological methodologies, in different time periods, geographic areas and populations have reaffirmed the existence of a protective effect of dissolved calcium and magnesium contents against the occurrence of CVDs[12]. Considering this evidence, the objective of this systematic review is to evaluate and synthesize the existing scientific evidence on the impact of high hardness water consumption, particularly calcium and magnesium content, on the incidence of myocardial infarction. Through a critical review of the literature, it is intended to provide an up-to-date and rigorous overview of current knowledge, identifying any gaps and proposing directions for future research.

Materials and methods

Study design

In order to proceed with the analysis of findings already found in scientific articles and other relevant texts, a literature review was conducted through a systematic method of searching for evidence.
The conduct of the review began by outlining the research question, using the PICO (Population, Intervention, Comparison, Outcome) methodology.

Table 1 - *Research question formulation according to PICO methodology.*

Population (P)	General population	Population, Urban population
Intervention (I)	Consumption of water with high levels of hardness	Drinking water, Water hardness
Comparison (C)	N.A.	N.A.
Outcome (O)	Prevention from the incidence of myocardial infarction	Primary prevention, Myocardial infarction

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Search strategy

The following review was conducted according to one of the most widely used international guidelines: the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) model[13,14]. Following the formation of the question to be researched, formulated through the PICO methodology, the following scientific databases were then consulted: Pubmed[15], CINAHL comprehensive16 and EMBASE17. The consultation of the databases started from May 1, 2024, until October 1 of the same year. During the search phase, the following Key words were used to circumscribe the field of investigation: "water hardness," "hard water," "myocardial infarction," "coronary diseases," and "heart diseases." For each MeSH (Medical Subject Heading term), respective synonyms were identified in the databases chosen to conduct the review.

Next, advanced search strings were set up in the different databases chosen, using the Bolean operators "OR" and "AND" to combine the terms into different combinations and make the search more specific.

The strings used are shown in the tables below.

Table 2 - *Queries on the Pubmed database*

	Search strings	Total results	Included results	Excluded results (not relevant)	Results excluded (no chance to download the full text)	Results excluded (because they have already been taken into account)
Pubmed	Drinking water AND water hardness AND myocardial infarction	16	8	2	6	0
	Drinking water AND water hardness AND coronary diseases	18	10	1	4	3
	Drinking water AND water hardness AND heart diseases	38	19	4	10	5
	Drinking water AND hard water AND heart diseases	44	5	4	2	33
TOTAL		116	42	11	22	41

Table 3 - *Queries on the complete CINAHL database.*

	Search strings	Total results	Included results	Excluded results (not relevant)	Results excluded (no chance to download the full text)	Results excluded (because they have already been taken into account)
CINAHL complete	Drinking water AND water hardness AND myocardial infarction	3	-	-	-	3
	Drinking water AND water hardness AND coronary diseases	7	1	3	-	3
	Drinking water AND water hardness AND heart diseases	9	1	1	-	6
	Drinking water AND hard water AND heart diseases	4	-	4	-	2
TOTAL		23	2	7	-	14

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Table 4 - *Queries on the EMBASE database*

	Search strings	Total results	Included results	Excluded results (not relevant)	Results excluded (no chance to download the full text)	Results excluded (because they have already been taken into account)
EMBASE	Drinking water AND water hardness AND myocardial infarction	22	2	8	-	12
	Drinking water AND water hardness AND coronary diseases	7	3	1	-	3
	Drinking water AND water hardness AND heart diseases	26	5	7	-	14
	Drinking water AND hard water AND heart diseases	8	-	3	-	5
TOTAL		63	10	19	-	34

Criteria for inclusion and exclusion

In the initial phase of the search, specific criteria for inclusion and exclusion of studies were defined and applied to the selected databases. No additional restrictions were imposed beyond the established inclusion and exclusion criteria, such as preference for English-language articles and availability of full text. Both primary studies (experimental and observational) and secondary studies (systematic reviews, literature reviews, and meta-analyses) were considered, as long as both full text and abstract were freely available. Articles that were not freely accessible, those under development (and therefore incomplete), and those not written in English were excluded. Duplicate articles were included only once to avoid repetition. Specific filters were applied for the following categories:

- Language: preference for articles in English;
- Age of participants: subjects over 18 years old.

Selection of studies

The survey yielded a total of 202 articles at preliminary stage (116 on Pubmed, 23 on complete CINAHL, and 63 on EMBASE).

From the total number of articles, 148 were excluded (see Table 6 for details).

Of the remaining 54 articles, the full text was examined to conduct a comprehensive survey.

After careful analysis of each article, this breakdown was arrived at:

Table 6 - *Final breakdown of articles*

Database	Related articles	Removed articles
Pubmed	*6*	*36*
CINAHL complete	*0*	*2*
EMBASE	*0*	*10*
TOTALE	*6*	*48*

Of the 54 articles included, 48 were excluded from the review because, upon reading the full text, they were found to be inconsistent with the established inclusion criteria or the requirements of the research objective, while 6 articles were included.

Each article was carefully examined for compliance with the predetermined criteria, and the methodology adopted was analyzed to ensure the reliability and validity of the results.

The detailed method used in selecting articles for this review is made evident through the following flowchart.

Table 5 - *Total items considered and excluded*

Total items considered	Total items included	Total items excluded (duplicates)	Total items excluded (no full text)	Total items excluded (not relevant)
202	54	89	22	37

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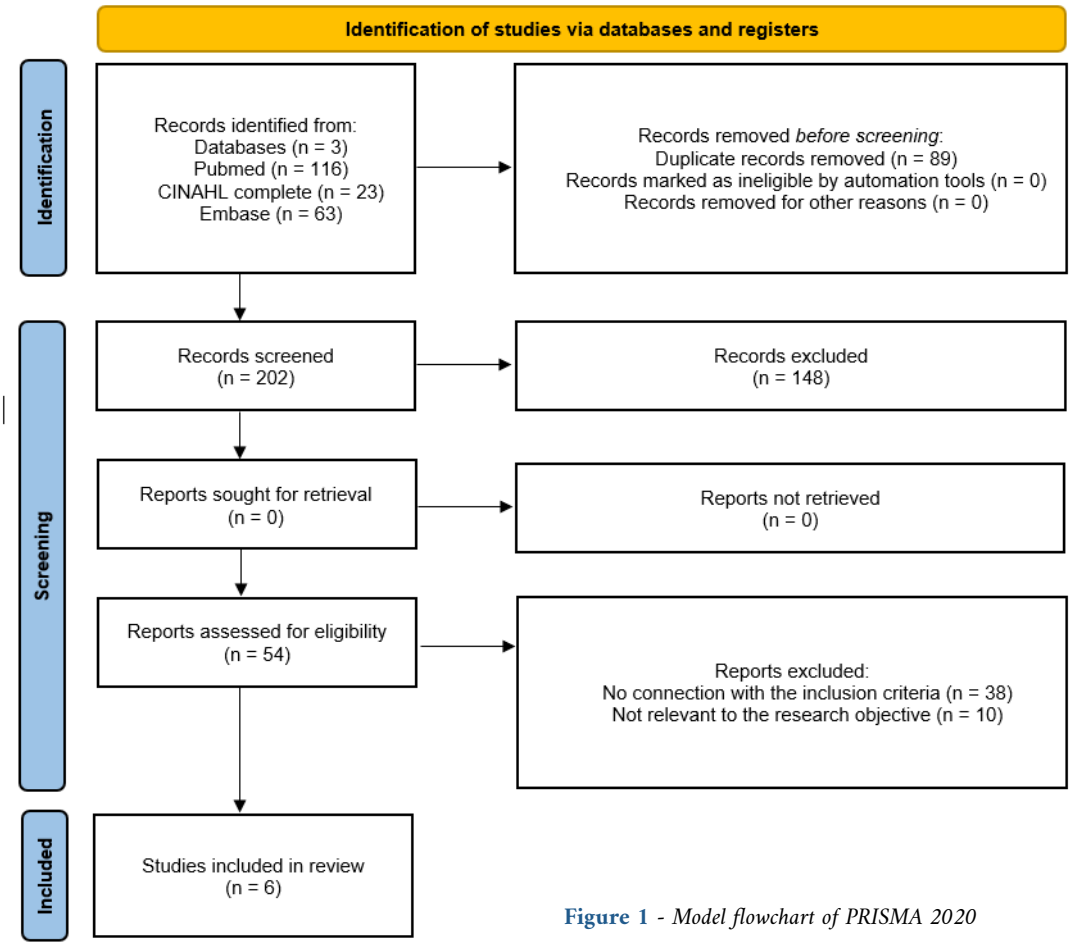

Figure 1 - *Model flowchart of PRISMA 2020*

Results

Six studies were analyzed to evaluate the relationship between consumption of water with high hardness with the presence of dissolved minerals (calcium and magnesium) and the incidence of myocardial infarction:

1. Taiwan Study[18] (case-control study): Formation of case group with people with myocardial infarction in the age range of 50-69 years and control group with absence of the pathological condition. The total number of myocardial infarction cases was 10,094 during 1994-2003. The mean calcium and magnesium concentrations were 33.6 mg/L and 11.3 mg/L, respectively, in the drinking water of the cases, while the controls had a mean calcium exposure of 36.3 mg/L and 11.8 mg/L for the controls. The results indicate a significant protective effect of calcium in drinking water on the risk of death from acute myocardial infarction (AMI), with odds ratios (ORs) of 0.79 and 0.71 in the groups with higher calcium levels;
2. Swedish study[19]: Selection of 44 Swedish municipalities with a water hardness range of 0.8 to 20.7 dH (German degrees of hardness). Waterworks in each municipality received a questionnaire requesting information on water hardness during the period 1955-1985. The final material included hardness data from 32 municipalities, from which water samples were requested for determination of calcium, magnesium, lead, and cadmium levels. Thus, complete analysis data were obtained from 27 municipalities and mortality data on ischemic disease and cerebrovascular disease for the period 1970-1980. The results showed a statistically significant relationship between the amount of magnesium and ischemic heart disease, but not cerebrovascular disease;
3. Ecological study[20] in Iran (Isfahan): was conducted by considering the cardiovascular mortality rate in the years 2013-2015 in 25 cities of Isfahan province. Initially, information was studied with respect to water hardness for three years in Isfahan province. Then, data were collected on cardiovascular disease mortality during 2013-2015. The calculation of the mortality rate in each of the three years in each of the 25 cities in Isfahan province was carried out. According to the results obtained, cities with higher water hardness have lower cardiovascular mortality rates;
4. Italian study[21] (Sardinia): Analysis of 377 territorial units, collecting data on mortality from myocardial infarction during 1981-1991 and water hardness levels. Significant inverse correlation between calcium in water and cardiovascular mortality; borderline correlation for

magnesium. Associations between water parameters and cardiovascular disease death counts were studied using a Bayesian conditional autoregressive (CAR) model. Consistent with previous studies, correlation analysis showed a significant inverse association between Ca2+ content and coronary heart disease mortality, while Mg2+ cation concentration showed a borderline trend in the same direction;

5. Canadian study[22] (Saskatchewan): residents were assigned a residence code based on their place of residence or mailing address. The first three digits of the residence code were used to assign study subjects to RMs (rural municipalities). In the present study, no evidence was found for associations between calcium and magnesium concentrations in groundwater and cardiovascular disease in rural Saskatchewan residents;
6. Swedish study[23] (Skåne and Blekinge): A questionnaire was sent to all 37 municipal offices asking about drinking water hardness, acidity, and water treatment procedures. Information on the incidence of myocardial infarction was for all women in the study area who had died between the ages of 50 and 69 during 1982-1993. The case group included women with a diagnosis of acute myocardial infarction, while the controls were women diagnosed with cancer. Despite the possible misclassification of exposure, a strong relationship was found; with a more precise measure of exposure, the relationship would probably have been even stronger.

Discussion

The literature review conducted investigated the potential protective role of high water hardness with respect to the risk of cardiovascular disease occurrence, with a particular focus on myocardial infarction. The results that emerged are encouraging: 5 out of 6 studies showed a positive correlation between water hardness and reduced risk of myocardial infarction. These studies found that the presence of minerals, such as calcium and magnesium, is associated with a protective effect on cardiovascular health.

In particular, magnesium is involved in the regulation of blood pressure and heart rhythm, as shown by previous studies that have highlighted its role in preventing hypertension and arrhythmias[5,6]. Calcium, on the other hand, is essential for muscle contraction and plays a key role in reducing oxidative stress at the cardiac level, helping to protect the myocardium from cellular damage[7,8].

This beneficial effect has been documented mainly in populations consuming water with high hardness, suggesting that consistent intake of these minerals may reduce the incidence of myocardial infarction. For example, the study conducted in Taiwan18 showed a significant reduction in the risk of myocardial infarction in areas with higher levels of calcium and magnesium in drinking water, supporting the hypothesis that these minerals have a protective effect. Similarly, the Swedish study[19] showed an inverse correlation between magnesium concentration in water and mortality from ischemic heart disease.

Pathophysiologically, magnesium exerts cardioprotective effects through regulation of cellular ion channels, with demonstrated reduction in arrhythmic risk[5,6], while calcium stabilizes myocardial electrical homeostasis and reduces oxidative stress[7,8]. Although these mechanisms are supported by experimental studies, their clinical validation in humans requires further investigation.

Furthermore, these results support the hypothesis that monitoring and intervention policies to ensure adequate mineral content in drinking water may be a promising strategy for the prevention of cardiovascular disease, particularly myocardial infarction, at the population level. For example, implementing programs to enrich drinking water with calcium and magnesium could be an effective measure to reduce the incidence of these diseases, especially in geographic areas with low natural levels of these minerals[12,20].

However, it is important to consider that the protective effect of water hardness could vary depending on factors such as overall diet, lifestyle, and genetic characteristics of the population. Future studies should explore these interactions to identify the optimal conditions under which water with high hardness can maximize its benefits on cardiovascular health.

Limitations and strenghts

This review has some limitations, which could affect the transferability of the research results.

The first limitation concerns the selection of papers conducted on three databases, with the application of very stringent inclusion criteria. In particular, studies written in languages other than English and those that were related to a disease/condition other than the one being researched were excluded. This decision may have limited the completeness of the picture provided by the information collected.

In addition, some studies included in the review involved small populations, which may limit the generalizability of the results. An additional limitation concerns the inclusion of studies conducted between the 1970s4 and 1990s[19,23]. Their inclusion is justified by their pioneering role in identifying the relationship between water hardness and cardiovascular health; however, differences in environmental factors, lifestyles, and medical therapies compared with contemporary populations could affect the transferability of the results.

Strengths of this review include the multiplicity of outcomes examined with the aim of providing a broader view of the big picture and the faithful and

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clear documentation of the various steps involved in selecting the various papers for inclusion.

Conclusions

It is very common in the population that water with a high degree of hardness may be a problem for kidney stones; this belief has been scientifically disproved through numerous studies internationally.

In light of the evidence, consumption of water with adequate levels of calcium (100-150 mg/L) and magnesium (≥50 mg/L) could be a complementary preventive intervention in populations at cardiovascular risk, particularly in areas with naturally mineral-poor waters.

However, standardization of optimal thresholds and supplementation with drug therapies (e.g., diuretics) require verification through controlled clinical trials. In addition, given the benefits of water with adequate calcium and magnesium concentrations, consistent consumption would lead to managing the economic impact of this category of disease on the very looming public health system. The only tool that can change citizens' thinking is information, a tool that can clarify any doubts rooted in the traditions of entire communities.

Nevertheless, we reiterate the need for further research examining larger populations to assess with greater certainty the possibility of universalization of results and thus the applicability of this type of habit in daily life.

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