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ORIGINAL RESEARCH ARTICLE

The Monetary Value of a Statistical Life in the Context of Atherosclerotic Cardiovascular Disease

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Abstract

Aim This study aims to estimate the value of a statistical life (VSL) in the context of atherosclerotic cardiovascular disease (ASCVD) in Spain using a contingent valuation/standard gamble (CV/SG) chained approach.

Methods The study employed a two-stage preference elicitation method that combined contingent valuation and a modified standard gamble technique. Specifically, willingness-to-pay and willingness-to-accept values were obtained for two health states depicting hypothetical outcomes following cardiovascular events. Subsequently, relative utility losses for the health states were derived using a modified standard gamble framing two risky choices. Chaining these elicited values allowed for VSL calculation without requiring direct valuation of small mortality risk reductions. The study was conducted through in-person interviews with a representative sample of 412 Spanish adults selected by stratified quotas.

Results The estimated VSL range is from 1.59 to 2.06 million euros. Minor differences emerge between VSL figures on the basis of each of the two health states. These VSL estimates for ASCVD are congruent with the recent update of the official VSL estimated for Spain in the context of road traffic accidents, though the upper limit of the range is slightly higher (almost 9%).

Conclusions VSL estimates align with existing ranges in other European countries, particularly in the context of road safety, where a significant portion of existing studies is concentrated. Comparisons with other contexts, involving cardiovascular diseases, also lend support to the estimates presented here.

1 Introduction

Atherosclerotic cardiovascular disease (ASCVD) is a condition where atheroma plaque builds up inside the arteries, leading to impaired blood flow and ischemia, which frequently is associated with acute events such as heart attacks and strokes. Atherosclerosis is a pathological process where cholesterol, mostly low-density cholesterol particles, and other substances accumulate on artery walls, forming plaques that impede blood flow and are prone to rupture, which causes thrombosis and acute ischemic events [1]. In Western societies, and particularly in Spain, ASCVD holds significant importance owing to its high prevalence and impact on public health. It is one of the leading causes of death and a major cause of disability over the world [2].

According to the Spanish Statistical Office [3], cardiovascular diseases (CVDs) were the leading cause of death in Spain in 2022, provoking more than 121,000 deaths (26.1% of total deaths). Underlying atherosclerotic pathophysiology contributes decisively to CVD burden, in terms of premature deaths and years lived with disability [4–6]. This is the case in Spain, the country where our study was conducted, where ischemic heart disease (IHD) and cerebrovascular disease are the two most frequent causes of death, amounting to almost 54,000 fatalities and 44.3%

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Key Points for Decision Makers

The value of a statistical life (VSL) is a significant measure used in health economics and policy to quantify the societal value of reducing mortality risks. Most VSL estimates are derived from traffic accident contexts or environmental risks, with limited application to cardiovascular diseases.

This paper applies the contingent valuation/standard gamble (CV/SG) chained approach to estimate VSL in the context of atherosclerotic cardiovascular disease (ASCVD) in Spain. The VSL estimates range between 1.59 and 2.06 million euros.

The VSL estimates derived from ASCVD contexts offer valuable benchmarks for health policy and economic evaluations. These insights can inform resource allocation decisions, cost-effectiveness analyses, and healthcare interventions aimed at reducing cardiovascular mortality in Spain and potentially across Europe.

of all deaths due to cardiovascular problems. Prevalence of these two CVDs in Spain were 22.9 and 16.4 per 1000 inhabitants, respectively, in 2021. Prevalence increases with age, so IHD exceeds 10% for males aged 70 years and over, whereas cerebrovascular disease can even affect 10 out of 100 people aged 80 years and over [7].

As previously mentioned, the CVD burden in terms of premature deaths and years lived with disability is considerable. This study primarily aims to estimate the economic impact of this burden for Spain. A significant portion of the CVD burden relates to premature mortality, which we seek to quantify economically using the value of a statistical life (VSL). The VSL represents the monetary amount that society is willing to pay to prevent one statistical or anonymous fatality. Such a value is derived from the aggregation of people's willingness to pay (WTP) for a small reduction in the risk of death [8, 9]. For example, if each individual is willing to pay 1€ to reduce the risk of dying by 1 in 1,000,000, then a population of 1 million individuals would be willing to pay 1€ million to save one statistical life. Therefore, a VSL of 1 million euros results.

There are different approaches to estimate the VSL. One of them is to observe how individuals behave in the market. For instance, the wage compensation that workers require to accept a higher risk at their jobs [9–11]. Methods of this type are called "revealed-preference" methods. However, "stated-preference" studies, such as contingent valuation (CV) surveys or discrete choice experiments (DCE), rely on what individuals say that they would do under hypothetical circumstances [12, 13].

CV studies use surveys to elicit individuals' WTP to reduce the risk of death and/or their willingness to accept compensation (WTA) for an increase in the risk of death. A major issue with this method is the ample evidence suggesting that CV valuations often suffer from scope insensitivity [14, 15]. Specifically, while the theory [16] predicts that individuals' WTPs should be proportional to the size of risk reduction, it is commonly found that WTP is significantly less than proportional to minor reductions in the risk of death [17, 18]. Thus, VSL estimates change with the size of risk reduction [19, 20].

In DCE studies, participants must choose their preferred option from a series of alternatives. Each variant of the hypothetical good is described by a set of attributes, including the price or cost to the respondent [21]. This allows the analyst to estimate the monetary value that people attach to the good. One important problem of DCE is the high occurrence of lexicographic preferences, which is the tendency to choose consistently between options solely on the basis of an attribute, as found in many studies [22–25].

Although VSL has been estimated mostly in the context of traffic accidents [14, 23, 26–31], there are also VSL estimates for other different environments, such as air pollution [32, 33] or heat waves [34], as well as for specific causes of death, such as cancer [29, 35–39], respiratory illness [29, 32, 35], and cardiovascular disease [32, 34].

As Nankunda and Evdorides [40] argue, there is a third stated-preference approach, different from DCE and CV methods, but closely related to the latter, called the "contingent valuation/standard gamble (CV/SG) chained approach." This method, developed by Carthy et al. [41], was intended to overcome the problems of CV valuations previously mentioned, particularly, the fact that those valuations usually lack sensitivity to scope. This problem is attenuated by, first, eliciting WTP and WTA estimates for avoiding or compensating for suffering from a nonfatal health state certainly, and next, combining those estimates with answers to standard gamble (SG) questions. These questions ask respondents the risk they are willing to accept to avoid premature death and can be posited in two different ways. In the traditional way [42], a risky treatment (i.e., a gamble or lottery) that can lead either to the recovery of full health or to death is compared with an impaired health condition with certainty. Probabilities of the gamble are varied until participants are indifferent between the two alternatives. However, as has been often reported (e.g., [19]), many respondents are reluctant to make trade-offs between risk of death and health improvement, a bias that can be explained by means of the so-called "certainty" effect [43]. To mitigate this propensity to outweigh the certainty embodied in the sure outcome against the risk of dying, Carthy et al. [41] proposed a "modified" standard gamble (MSG), called this way because it compares two gambles with each other instead of comparing a gamble and a sure outcome. In this way, as shown by Abellan-Perpiñan et al. [44], this framing diminishes respondents' reluctance to accept any risk of fatality enabling preference elicitation.

The CV/SG chained method has been used to estimate the VSL in Spain [45, 46] in the context of traffic accidents and, to our knowledge, that is the only context in which it has been applied up to now. This manuscript extends the use of the CV/SG chained method, which attenuates the limitations of classical CV and SG procedures, to the domain of cardiovascular risks. This is the first time that this method is used to estimate the VSL in the specific realm of cardiovascular risks.

The paper is organized as follows. In the next section the study design is described in detail, including the preference elicitation methods and the questionnaire administered to participants in the survey. Section 3 shows the main findings of the study. VSL estimates for two health states representative of the health condition following a heart attack and a stroke are presented. The discussion section reflects on the major contributions and limitations of this study, offering a critical and contextual analysis. The paper ends with a conclusions section.

2 Methods

2.1 The Contingent Valuation/Standard Gamble (CV/SG) Chained Approach

The CV/SG chained approach combines (i.e., "chains") the responses to two types of questions, thus splitting the valuation of risk reductions into three steps:

1. The marginal rate of substitution (MRS) between wealth and the risk of a nonfatal health problem i (denoted by m_i) is inferred from WTP and WTA estimates by assuming a specific functional form of the utility function.

2. A MSG question is used to estimate what Carthy et al. [41] call the "relative utility loss" (RUL) or m_d/m_i, where m_d is the MRS between wealth and the risk of death. More specifically, subjects are asked to establish indifference between two binary lotteries X and Y. Assume that $X =$ (death, q;injury, i) and Y = (death, p;normal health), where q and p are the probabilities of death in X and Y, respectively. Assume that q is fixed at a predetermined value (1 in 1000 in Carthy et al.). Subjects have to state the value of p that leaves them indifferent between X and Y. If subjects are expected utility maximizers then:

$$\frac{m_d}{m_i} = \frac{(1-q)}{(p-q)}. \tag{1}$$

3. Finally, since we know m_i from WTP/WTA questions and $(1-q)/(p-q)$ from MSG, the theoretical result in (1) makes it possible to infer m_d:

$$m_d = \frac{(1-q)}{(p-q)} \times m_i. \tag{2}$$

For each individual, m_d for nonfatal health problem i will be computed. Subsequently, these individual assessments are aggregated to calculate the mean, yielding the societal VSL.

Note that the relevant advantage of this method is that m_d can be estimated without asking subjects WTP questions about very small risk reductions, which is a significant benefit of the CV/SG method.

A different chained procedure was suggested by Carthy et al. [41] that they called the "indirect" method. This procedure consisted of using an intermediate health state j, less severe than the state i, used in the CV/SG approach. A second MSG question is used to calculate the RUL of state j compared with i (m_i/m_j), and this result is multiplied by m_d/m_i to obtain m_d/m_j. Finally, they chain this result with the MRS between wealth and health state j, derived from the WTP to avoid suffering state j and the WTA in compensation for suffering from state j, thus estimating m_d.

The "indirect" method was proposed as a consistency test of the CV/SG approach since, theoretically, its results should be the same as those from the "direct" method. As this was not the case in Carthy et al.'s study, some concerns emerged in relation to the consistency of the method. Sánchez Martínez et al. [31] introduced an alternative "indirect" or "double chained" method, which utilized an intermediate health state that was more severe, rather than milder, than state i. The RUL of this health state k with reference to i is obtained through an MSG question, as well as the RUL of death with respect to k. The product of these two RULs (m_k/m_i and m_d/m_k) allows us to obtain m_d/m_i, and this value is finally multiplied by the MRS between wealth and the health state i to estimate the VSL. The alternative indirect method tried by Sánchez Martínez et al. [31], though it also led (as reported previously by Carthy et al. [41]) to a higher VSL than that yielded by the direct method, appears to have contributed to reducing such discrepancy. Therefore, we opted to apply the same indirect method [31] in the present study to assess whether, in a different context, it could reliably generate values comparable to those obtained through the direct method.

2.2 Study Design

A representative sample of the general Spanish population by gender and age quotas was obtained through a two-stage stratified sampling methodology. Participants were recruited in person, and interviews were conducted at their homes to ensure a comfortable and controlled survey environment. The data collection was carried out by a professional firm specialized in survey administration, using computer-assisted personal interviews (CAPI). Fieldwork took place from August to October 2023 in four Spanish autonomous communities—Andalusia, Madrid, Catalonia, and the Region of Murcia. The initial target sample size was 474 participants to achieve a 4.5% margin of error at a 95% confidence level. The response rate was 86.9%, so the final sample amounted to 412 respondents. The final sample distribution closely aligns with the demographic structure of the Spanish adult population.

2.3 Health States Selected

In principle, a unique health state is needed to apply the CV/SG chained approach to estimate the VSL. Notwithstanding, two distinct health states were used in this study, for two reasons. First, there is plenty of evidence suggesting that VSL estimates are context dependent [47]. This does not mean exclusively that the cause of death per se (e.g., CVD) seems to account for a considerable part of the VSL [29, 34], but also that, even for the same cause of death, the VSL is not constant with respect to the magnitude of the mortality risk reduction [15]. Furthermore, studies that have attempted to estimate the monetary value of a quality-adjusted life-year (MVQALY) typically find that estimated values depend on both the severity and the duration of the health state used [48, 49]. In view of this evidence about variability of VSL and MVQALY, we first analyzed whether VSL estimates in the context of CVD may also depend on the health state used. Second, using two different health states also allowed us to apply the "indirect" chained approach described above to check the consistency of the CV/SG method. The two health states used are depicted in Table 1. They have been described to reflect two possible outcomes of a different severity following a cardiovascular event. One of them tries to represent a situation after suffering a heart attack and the other one a situation after a stroke. Both states implied time spent in hospital: 1 week in the case of state *X* and 2 weeks in the case of state *Y*, and they have the existence of some mobility problems and some difficulty for concentrating on certain tasks in common, such as reading or writing. However, the symptoms are more severe in state *Y*, which also imposes more constraints on the ability to work, both outside and inside the home. In that sense, the two states can be "logically" ordered, representing state *Y*, which is a clearly worse situation than that described by state *X*.

2.4 Preference Elicitation Methods

2.4.1 Contingent Valuation

The initial phase of the CV/SG methodology entails obtaining the maximum WTP to avoid a health issue and the minimum WTA in compensation for enduring the same condition. A set of payment cards, each representing a distinct amount in euros, is employed to solicit both WTP and WTA responses. For WTP questions, participants are required to specify whether they would definitely pay, definitely not pay, or remain uncertain about each euro amount to ensure the avoidance of the health issue. Regarding WTA questions, respondents must determine whether each proposed sum would be sufficient, insufficient, or if they are uncertain whether it would adequately offset the health loss detailed in the evaluated health state. In both cases, the payment cards were presented in a randomized sequence to prevent any bias. After gathering all responses, an open-ended question was introduced to further refine the respondents' WTP to avoid the health state within the range from the highest amount they would willingly pay to the lowest amount they would either refuse or be uncertain about paying. In a similar manner, another open-ended question sought to fine-tune the respondents' WTA, narrowing it

Table 1 Description of the health states used in the questionnaire

Health state *X*	Health state *Y*
In hospital	In hospital
1 week in hospital	2 weeks in hospital
After hospitalization	After hospitalization
Some mobility problems and some difficulty concentrating on some tasks, such as reading or writing	Some mobility problems and some difficulty concentrating on some tasks, such as reading or writing
The symptoms do not interfere with your usual activities to any appreciable extent but affect your ability to enjoy your daily life	Symptoms do not prevent you from bathing and dressing yourself, shopping, cooking, etc.
	Your situation prevents you from continuing your work outside the home, as well as from taking care of other people (children, elderly) inside the home

down to the interval between the smallest amount deemed adequate and the largest amount considered inadequate.

According to the theory [16], the MRS between wealth and the risk of death (m_d) can be estimated from WTP and WTA valuations, by assuming a specific functional form of the income utility function. In this study, four different forms were used: logarithmic, exponential, homogeneous, and *n*th root.

2.4.2 Modified Standard Gamble

The MSG used in this study asked individuals to choose between a gamble (a medical treatment) denoted by (death, p;normal health), yielding normal health with probability $(1-p)$ and death with probability p and another gamble denoted by (death, q;health state$i$), yielding health state i with probability $(1-q)$ and death with probability q. Probability of death in the second gamble, q, is fixed at 1 in 1000 (0.001), as in Carthy et al. [41] and Sánchez-Martínez et al. [31]. Participants have to state the value of p that leaves them indifferent between the two gambles ($p*$).

Assuming expected utility and considering that the utility of perfect health is 1 and the utility of death is 0, then the utility of the health state i is obtained as:

$$U(i)=\frac{1-p*}{1-0.001}$$

The MSG questions needed to apply the "indirect" method are equal or similar to the one described. In the case of the question aimed to obtain the RUL of the intermediate state k with reference to i, health state k takes the place of death in the gambles, and the probability of death in the second prospect is fixed at 1 in 100 (0.01).

A choice-based matching procedure [50] was used to find probability. This procedure estimates $p*$ by using a convergent sequence of choices between treatments A and B on the basis of the "bisection" method, until an interval containing $p*$ is produced. Afterwards, respondents were asked an open-ended question to establish the exact value of $p*$ within the interval. The same procedure was used in all MSG questions.

2.5 The Questionnaire

The questionnaire contained 27 questions, grouped into five sections. In Sect. 1, participants were informed about ASCVD and the risk of suffering cardiovascular events from ASCVD, using a risk ladder that puts this risk in the context of other health risks. After that, participants were asked about their habits related to physical activity, nutrition, smoking, and alcohol intake. Some additional questions were aimed at testing the respondents' ability to understand risks expressed in different ways (i.e., 1 out of 100 compared with 10 out of 1000, for instance).

In Sect. 2, the health states describing two hypothetical scenarios following a cardiovascular event—anonymously labeled as X and Y—were shown to participants. Next, participants had to score these two states on a 0–100 visual analogue scale (VAS), together with their own health state at the moment of being interviewed and immediate death.

Section 3 contained the CV part, that is, the questions aimed at obtaining the respondents' WTP to avoid suffering each of the two health states, X and Y, and their WTA in compensation for suffering both states. Participants were asked first to reveal their WTP and WTA for health state X, following the mixed format previously described (i.e., payment cards and a final open-ended question), and then they had to answer the same questions with health state Y. The euro amounts included in the cards were the following: 50; 100; 300; 500; 1000; 3000; 10,000; 30,000, and 100,000 €.

In Sect. 4, MSG questions were included. After a brief introductory explanation of the framing of questions, participants were asked to choose between gambles involving health state X, that is, they face a series of choices between treatment A:$(X, 0.999;\text{death})$ and treatment B:$(\text{full health}, (1-p_x);\text{death})$, where p_x changes according to the respondent's choice. Once the value of p_x that made the individual indifferent between the two treatments was been obtained, a second question, using the same procedure, was posed by replacing health state X by health state Y, that is, participants must choose between treatment C $(Y, 0.999;\text{death})$ and treatment C $(\text{full health}, (1-p_y);\text{death})$.

A third MSG question asked the interviewees to choose between treatment E: $(X, 0.99;Y)$ and treatment F: $(\text{full health}, (1-p_{xy});Y)$, aimed at eliciting the relative utility loss of Y compared with X. Following the first two MSG questions and after the third one, participants were asked to state which elements of the scenarios influenced their answers the most (e.g., the risk of death in treatment B, the description of the health states, the probability of recovering full health in each of the treatments, etc.).

Finally, Sect. 5 collected some basic characteristics about respondents, such as gender, age, and education level, their subjective probability of survival at different ages (75, 80, …95 years), and the degree of difficulty of the questionnaire, on a scale from 0 (none) to 10 (maximum).

The full questionnaire translated into English, including some screenshots of the computer interface, is included as part of the Supplementary Material.

2.6 Statistical Methods

In our study, we employed both parametric and non-parametric statistical tests to analyze the variables of interest in the paired samples from states *X* and *Y*. Specifically, we used the *t*-test (parametric) and the Wilcoxon signed-rank test (non-parametric) to assess the differences in WTP, WTA, risks assumed with the MSG, scores from the VAS, and the VSL estimates, according to the four functional forms.

In addition, we conducted a series of regression analyses to ascertain the theoretical validity of the contingent valuation method utilized. Central to affirming this validity is establishing a positive and statistically significant correlation between an individual's income level and their WTP. Specifically, the regression analyses target three key variables: WTP to avoid health state *X*, WTP for health state *Y*, and aggregate WTP (encompassing both states *X* and *Y*). For these analyses, we employed the logarithmic transformation of the WTP figures as dependent variables, mirroring this transformation for the income variable. This technique was strategically chosen to facilitate the calculation of income elasticity. Our model also integrates a range of control variables, such as age, gender, and educational attainment. In addition, lifestyle-related variables are included to provide a more holistic view, encompassing factors such as tobacco consumption, alcohol intake, and physical exercise frequency. Pertinently, the model incorporates health-related variables, including the visual analogue scale (VAS) assessments of both the respondents' own health status and the health state being evaluated, body mass index, the likelihood of survival to specified ages (ranging from 75 to 95 years), and the self-perceived risk of mortality due to atherosclerotic cardiovascular diseases. In addition, variables related to the degree of risk comprehension, numerical skills, and subjective difficulty were also included. Regional control variables were integrated into the model to account for geographic variations among the respondents.

3 Results

3.1 The Sample

Average time per interview was about 20 min (median 14 min 31 s). All 412 questionnaires were fully completed, and as a result, they were considered valid for analysis. Sociodemographic and attitudinal characteristics of our sample can be seen in Table 2.

3.2 Contingent Valuation Estimates: WTP, WTA, and Marginal Rates of Substitution

WTP and WTA statistics are presented in Table 3. Nine respondents with health state *X* and eight with health state *Y* refused to pay any amount of money for any treatment (WTP = 0), but those subjects were not excluded from the analysis.

We can see that WTP and WTA values are sensitive to scope. Both WTP and WTA values are higher for state *Y*, which is perceived as more severe than state *X*, consistent with its lower VAS ratings (Table 4). Both parametric and nonparametric tests confirm that there are statistically significant ($p < 0.01$) differences in WTP and WTA values between the two health states (Supplementary Material, Table S1).

In addition, the theoretical validity of WTP estimates was tested by regression analysis (Supplementary Table S2). The results show a positive and significant relationship between individuals' income and their WTP. Furthermore, the income elasticity values obtained, around 0.6, align with those typically reported in literature.

3.3 Results of the Modified Standard Gamble (MSG)

Table 5 presents the results of the MSG questions. Firstly, the indifference probabilities exhibit sensitivity to scope, meaning that respondents' willingness to accept a certain risk varies depending on the severity of the health state being avoided. Specifically, both the mean and median values of the risk of death that respondents are willing to take to avoid health state *Y* (p_y) are higher than those for health state *X* (p_x), which represents a less severe condition ($p \leq 0.001$ in both the *t* test and Wilcoxon signed-rank test). Similarly, in the scenario presented during the third MSG, where state *Y* replaces death as the worst outcome, respondents were willing to take a significantly higher level of risk (p_{xy}) compared with scenarios where death (p_x) was the worst outcome ($p <$ 0.001 in both the *t* test and Wilcoxon signed-rank test). This highlights how respondents perceive death as a much worse outcome than health state *Y*, demonstrating their sensitivity to the severity of the worst possible consequence in the decision-making process.

A relatively high number of participants refused to assume more than a minimum risk. This number is higher in the first MSG question (state *X*), with 45 respondents, than in the second (state *Y*), with 23 participants, and third (state *X* versus state *Y*) ones, with 5 subjects.

RULs are higher for state *X* than for state *Y*, which means that state *X* is closer to full health than state *Y* is. In fact, the utility estimate for state *X* is 0.926 and for state *Y* is 0.768.

Table 2 Characteristics of the sample ($n = 412$)

Variables	Sample (%)	Spanish population[a]
Gender		
Male	49.2	48.5
Female	50.7	51.5
Age (years)		
18–24	10.2	8.9
25–34	12.4	13.4
35–44	16.7	16.6
45–54	21.6	19.6
55–64	16.3	16.9
≥ 65	22.8	24.4
Education		
No education or primary	16.3	15.8
Secondary	50.0	50.8
Tertiary	33.7	33.4
Household income (€)		
Up to 1500 €	38.3	
1501–2500 €	47.1	
More than 2500 €	14.6	
Average disposable income (year)	21.156	19.160
Physical activity		
None	36.7	50.7
Occasionally	14.1	13.2
Regularly	49.3	36.1
Diet		
Mostly vegetables or vegan	15.3	8.9
Varied and balanced	34.5	36.8
All products/not worried about	50.2	54.3
Body mass index		
< 18.5	1.2	2.0
18.5 ≤ BMI < 25	51.2	44.3
25 ≤ BMI < 30	35.7	37.6
BMI ≥ 30	11.9	16.0
Smoking		
Never	51.0	55.8
Gave up	24.3	22.0
Occasionally	3.6	2.3
Daily	21.1	19.7
Alcohol intake		
Never	32.0	34.5
Occasionally/on weekends	49.5	44.9
Several days a week/daily	18.4	20.5

[a]European Health Survey (2020); Continuous Population Statistics, October 2023; Living Conditions Survey 2022 and Spanish Labor Force Survey (3rd quarter of 2023)

3.4 Value of a Statistical Life (VSL) Estimations

Different VSL estimates are derived depending on the specific functional form assumed for the income utility function.

Table 3 Willingness to pay (WTP) and willingness to accept (WTA) in euro to avoid/accept health states *X* and *Y*

	WTP		WTA	
	X	*Y*	*X*	*Y*
Mean	7293	15,305	13,692	243,916
St. dev.	13,366	29,592	21,135	691,716
Median	4400	13,000	8000	21,000

St. dev. standard deviation

Table 4 Visual analogue scores for states *X*, *Y*, own health state, and death ($n = 412$)

	X	*Y*	Own	Death
Mean	70.1	61.0	87.0	3.5
St. dev.	12.3	13.4	13.9	6.5
Median	69.5	61.0	90.0	0.0

St. dev. standard deviation

Table 5 Modified standard gamble (MSG) results: probabilities and health state utilities ($n = 412$)

	Maximum risk taken			Utilities	
	p_X	p_Y	$p_{X/Y}$	$U(X)$	$U(Y)$
Mean	0.037	0.116	0.538	0.926	0.768
St. dev.	0.062	0.123	0.261	0.123	0.246
Median	0.010	0.056	0.500	0.980	0.889

St. dev. standard deviation

Table 6 presents the results obtained using all valid observations, without excluding any extreme values. The first rows of the table report the estimates derived from the “direct” CV/SG method. Mean VSL estimates based on state *Y* (the more severe health condition) are higher than those based on state *X* (the milder condition). These values range from 3.2 million euro (*X*-based with the negative exponential function) to 6.6 million euro (*Y*-based with the *n*th root function). Conversely, median values are larger for VSL based on health state *X* valuations than for those based on health state *Y*. It is evident that median values are significantly lower than mean estimates, ranging from 281,631 € (*Y*-based, homogeneous function) to 724,122 € (*X*-based, *n*th root function).

The “indirect” CV/SG method yields VSL estimates that are significantly higher than those obtained with the “direct” approach. Mean figures range from 12.2 to 14.8 million euro, depending on the functional form which is assumed. This result is closer to that reported by Carthy et al. [41] using the original indirect method than to that obtained by Sánchez-Martínez et al. [31], suggesting that the tendency of the

Table 6 Value statistical life (VSL) estimates in euro, based on the CV/SG "direct" and "indirect" methods (including outliers)

	Logarithmic	Homogeneous	*N*th root	Neg. exponential
Direct X-based				
Mean	3,427,728	3,217,006	3,825,904	3,175,138
St. dev.	9,173,854	8,938,748	9,834,931	8,900,373
Median	581,633	510,964	724,122	459,557
N	403	412	403	403
Direct Y-based				
Mean	5,332,208	4,150,814	6,636,803	3,784,476
St. dev.	20,862,025	15,433,653	27,416,921	13,678,077
Median	318,958	281,631	344,221	283,774
N	404	412	404	404
Indirect				
Mean	13,233,126	12,447,266	14,846,344	12,282,190
St. dev.	64,058,709	60,556,635	73,628,172	58,557,539
Median	1,310,451	1,228,846	1,499,685	1,210,806
N	403	412	403	403

St. dev. standard deviation

Table 7 Value statistical life (VSL) estimates in euro, based in the CV/SG "direct" and "indirect" methods (trimmed values)

	Logarithmic	Homogeneous	Nth root	Neg. exponential
Direct X-based				
Mean	2,566,552	2,375,074	2,932,055	2,318,290
St. dev.	4,620,843	4,316,502	5,333,134	4,151,704
Median	581,633	510,964	724,122	458,251
N	397	406	397	397
Direct Y-based				
Mean	2,400,955	2,064,456	2,758,361	2,006,803
St. dev.	6,373,006	5,952,797	7,172,795	5,862,571
Median	313,595	247,976	331,466	243,972
N	392	400	392	392
Indirect				
Mean	8,403,471	7,888,777	9,394,106	7,789,069
St. dev.	21,541,108	20,838,118	23,533,712	20,613,287
Median	1,303,499	1,197,349	1,494,504	1,190,041
N	398	407	398	398

Individuals whose VSL estimates were larger than 3 standard deviations of the mean have been excluded

St. dev. standard deviation

"indirect" method to accumulate errors due to the chaining of additional linkages seems to be an intrinsic characteristic of this approach.

Precisely because some extreme values exist, we decided to discard some observations that could be considered as outliers. Specifically, individuals whose VSL values were greater than three standard deviations of the mean were excluded from the analysis, and the results are presented in Table 7. It should be noted that this trimming procedure only excludes six participants, although it has a significant impact on the estimated values, to the extent that the mean values based on *X* now surpass those based on *Y*, mirroring the pattern observed with the medians.

Mean VSL estimates based on the "direct" CV/SG method are between 2.0 million euro (*Y*-based, negative exponential) and 2.9 million euro (*X*-based, *n*th root). Median values are similar to those obtained prior to applying the trimming procedure and range from 243,972 € (*Y*-based, negative exponential function) to 724,122 € (*X*-based, *n*th root function). This trimming procedure also impacts the mean VSL estimates resulting from the "indirect" approach, which, after excluding five outliers, were reduced to an interval between 7.8 and 9.4 million euro.

One interesting result is that our VSL estimates do not vary dramatically depending on the health state (*X* or *Y*) on which they are based. Although figures in Tables 5 and 6 appear to differ between *X*-based and *Y*-based VSL estimates, the results of the *t* test suggest that the null hypothesis cannot be rejected. Notwithstanding, the nonparametric test (Wilcoxon signed-rank test) shows statistically significant differences at a 95% confidence level, for the VSL estimates derived with the homogeneous and the negative exponential function, and at a 90% for the estimates based on the other two functional forms. Parametric and nonparametric tests conclude that statistically significant differences exist between VSL estimates based on the "direct" and the "indirect" approach.

In the process of determining a specific value for the VSL derived from this study, it is reasonable to adhere to the principles of welfare economics. This implies providing a value on the basis of mean figures, as this method effectively represents aggregate preferences. In this context, the average of the mean values obtained for the two health states amounts to nearly 2.43 million euros. Specifically, for health state *X*, the average reaches 2.55 million euros and for health state *Y*, it is just over 2.30 million euros. However, these figures should be adjusted downward to reflect evidence suggesting that the marginal utility of income, when conditioned on experiencing a nonfatal health state, may differ from that in a state of perfect health. It is common to apply a 15% reduction to reflect this difference, a value derived from the findings of Viscusi and Evans [51] in the context of workplace accidents. Consequently, the adjusted value for both states would be approximately 2.06 million euros, 2.17 million euros for health state *X*, and 1.96 million euros for health state *Y*.

Furthermore, it is evident that there are significant differences between the mean and median values we have obtained. This discrepancy, a frequent occurrence in this methodology as noted by Sanchez-Martínez et al. [31], makes it advisable to give some consideration to the median values. Following an approach similar to that proposed by Carthy et al. [41], we calculated an average estimate from the highest of the mean values and the lowest of the median values. In our case, this method resulted in a combined value of 1.59 million euros for both states (an *X*-based estimate of 1.69 million euros and a *Y*-based estimate of 1.50 million euros).

Combining both approaches—the one based on the average of the means and that based on the midpoint between the minimum median and the maximum mean—a range of values between 1.59 and 2.06 million euros emerges for the VSL in the context of ASCVD.

4 Discussion

In this study, we estimate the VSL for ASCVD using the so-called CV/SG chained approach proposed by Carthy et al. [31]. The chained method employed in this study decomposes the valuation task into two stages. The first stage relies on contingent valuation methodology, capturing individuals' WTP and WTA for a health state, while the second stage involves the health state valuation using a "modified" standard gamble technique. For our analysis, we used two health states that depict scenarios consistent with ASCVD. These health states were described with the assistance of clinical experts to ensure their accuracy and plausibility. To the best of our knowledge, this is the first time this approach has been used to ascertain the VSL in the context of ASCVD. The estimation was conducted in Spain with a balanced sample of 412 adults, selected to represent various age and sex groups. Although the sample is not fully representative territorially, the four autonomous communities in which the survey was conducted represent more than half of the total Spanish population. As a result of this study, we have derived a range for the VSL in the context of ASCVD, spanning from 1.59 to 2.06 million euros.

The range of values obtained is consistent with the recent update of the official VSL estimated for Spain in the context of road traffic accidents [46], which amounts to 1.9 million euros, as well as with figures used in other European countries for road safety program evaluations. A recent study [52] showed that the official cost per road traffic fatality in 29 European countries ranges from 0.7 to 3 million euros (2015, PPP-adjusted). Typically, VSL estimates from stated preference studies are lower than those from revealed preference studies. Our estimate follows this trend, being lower than the market VSL estimates for Spain (2.8–8.3 million euros), provided by Martínez and Méndez [53].

Not surprisingly, although values reported in this paper are congruent with the VSL estimate for road safety in Spain, they are not identical. The upper limit of the range (2.06 million euros) is indeed slightly larger (almost 9%), which mimics in some respect those studies founding evidence of a "cancer premium" [29, 35]. Nevertheless, the potential "premium" for avoiding a fatality caused by ASCVD that could be inferred from our estimations is, at best, modest.

Few studies have compared the VSL across different contexts involving cardiovascular diseases. A notable exception is the study by Guignet and Alberini [54], which quantified how property values varied with different mortality risks from pollution in the United Kingdom and Italy. They focused on mortality risks associated with cancer, cardiovascular diseases, respiratory diseases, and all causes. The study found mixed evidence for applying a "cancer premium" in cost–benefit analyses. Italian homeowners value reducing cancer risks more highly (VSL = 9.266 million euros) compared with cardiovascular and respiratory risks (VSL = 5.013 million euros), or unspecified causes (VSL = 5.353 million euros). In contrast, British homeowners appear to value reductions in the risk of dying from cardiovascular disease and from all causes similarly. Alberini and Scasny [34] use a series of choices between life-saving programs (during heat waves, on one side, and from three possible causes of death: cancer, cardiovascular causes, and road traffic accidents, on the other side). They found that a heat wave death was considered approximately the same as a cancer death, slightly more than a generic death from cardiovascular causes, and more than a traffic accident death. Alberini and Scasny [34] estimated a VSL of 2.2 million euros in Spain on the basis of WTP for reductions in the mortality risks associated with heat waves.

In Chesnut et al.'s [55] study, an assessment evaluated the public's WTP for health programs aimed at reducing mortality risks in Canada and the USA. Specifically, the study examined various levels of risk reduction (1, 2, and 5 in 10,000) for death due to cancer, heart attack, and pneumonia, employing two distinct methodological approaches: payment cards and discrete choice. A consistent finding was that there were no significant differences in the VSL for cancer or heart attack causes of death. The results suggest that the WTP for reducing the risk of death from pneumonia is likely less than 50% of that for reducing risks of death from cancer or heart attack.

A particularly noteworthy outcome of our study is that the resulting VSL values were very similar across the two different health states. In fact, with some of the utility functions used, we cannot rule out the possibility that the differences are not statistically significant. This suggests a level of consistency in VSL estimations across different health states, raising interesting questions about the sensitivity and specificity of VSL measurements in varied health scenarios.

However, the consistency test conducted through double chaining in our study, as is common in literature [41], has not been satisfactory owing to significant differences that continue to emerge. Even after using the alternative chaining method developed by Sánchez-Martínez et al. [31], the discrepancy recorded in our study is quite large, suggesting that the "indirect" method is intrinsically prone to yielding very high values. In our view, this proneness may be interpreted as a sort of upward bias owing to the low probability values obtained from the MSG questions. There is indeed extensive evidence that people often perceive small probabilities to be higher than their actual values. To correct this bias, rank-dependent utility [56] and prospect theory [57] quantitative corrections of nonlinear probability weighting could be applied.

The contingent valuation exercise conducted in this study demonstrates theoretical validity, evidenced by a significant and positive relationship between the respondents' income levels and their WTP. This correlation is a fundamental criterion for validity in such studies. The regression analysis performed in this study to test the theoretical validity of VSL estimates yielded income elasticity figures ranging from 0.60 to 0.72. This variation depended on the health state used for deriving the WTP values. These elasticity values align with recent meta-analysis findings in middle and high-income countries, which report a range between 0.55 and 0.85 [58]. Consistently, the income elasticity in our study is below 1, which is common in most related research [11, 59].

Our study has certain limitations. First, it only focuses on the monetary valuation of mortality risk through the VSL approach, whereas ASCVD's economic impact extends beyond mortality, including morbidity costs such as healthcare expenses, productivity losses, and diminished quality of life. While VSL is effective for valuing fatality prevention, assessing ASCVD's broader social costs would require considering nonfatal outcomes. Future research should address the estimation of the economic burden of morbidity due to ASCVD through approaches such as the MVQALY. This research agenda faces methodological dilemmas, such as, the choice of the most suitable perspective to fully capture quality of life losses. In this regard, estimates of the MVQALY are available for Spain, both from a "supply" perspective, i.e., as the opportunity cost of the healthcare resources [60], and from a "demand" perspective, i.e., as the societal value for a QALY [61].

Second, the chained method, as initially introduced by Carthy et al. [41], has been notably susceptible to the issue of outliers. In their seminal work, an ad hoc threshold was implemented to curtail the influence of outliers on the mean calculations. In our analysis, following the precedent set by Sanchez-Martínez et al. [31], we adopted a limit of three times the standard deviation to manage outliers. We acknowledge, however, that this approach to outliers is one of several possible methods. Furthermore, the method of aggregating preferences has been shown to significantly affect results, as evidenced in the MVQALY literature. Studies such as those by Gyrd-Hansen and Kjaer [62] illustrate that aggregated approaches (ratio of means) and disaggregated approaches (means of ratios) can lead to markedly different outcomes. Consequently, it is necessary to further explore in depth how apparently irrelevant factors, such as the way of excluding outliers or the approach used to aggregate individual values, can affect VSL estimates.

Another limitation of our study is the relatively small sample size, which encompassed only 412 observations. While this sample size is relatively common in studies of this nature, it might limit the generalizability of our findings. In addition, our study focuses exclusively on atherosclerotic cardiovascular disease, which may not represent other health contexts where VSL estimations are applicable fully. Further research with larger and more diverse samples, as well as across different health contexts, would be beneficial to validate and expand upon our findings. Also, a limitation of the study is the potential lack of extrapolation to other countries. Cultural characteristics may significantly influence how individuals in different nations value certain disabilities or health conditions. This is evident in the case of multi-attribute utility systems such as EQ-5D [63] or SF-6D [64], where notable differences in valuations are observed across countries. Such cultural variances suggest that our results, while robust within the Spanish context, might not accurately reflect the values and perceptions in other cultural and national settings.

5 Conclusions

This study provides new empirical estimates of the value of a statistical life (VSL) in Spain using the so-called contingent valuation/standard gamble (CV/SG) chained approach proposed by Carthy et al. [31]. By applying this methodology in the context of atherosclerotic cardiovascular disease (ASCVD), we have derived a VSL range spanning from 1.59 to 2.06 million euros. The range of values obtained aligns with the recent update of the official VSL estimate for Spain in the context of road traffic accidents [46] and with figures used in other European countries for road safety program evaluation. These results have significant implications for health policy, economic evaluation, and regulatory decision-making, as VSL estimates are significant for resource allocation, cost–benefit analyses, and assessing the societal value of mortality risk reductions.

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Declarations

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Data availability statement The data that support the findings of this study are available upon reasonable request.

Ethical approval The study was approved by the Research Ethics Committee of the University of Murcia, which reviewed all submitted documentation and unanimously issued a favorable ethical assessment on 18 May 2023.

Consent to participate Informed consent was obtained from all individual participants included in the study.

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