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How Secondary Interventions Reduce the Burden of Alcohol Consumption at Risk of Cirrhosis: A Public Health Decision-Making Model

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ABSTRACT

Background: Better understanding of the kinetics of the consumption of alcohol at risk of cirrhosis (≥ 20 g/day) and the prediction of the burden of alcohol consumption are needed for public health decision-making.

Methods: Based on individual data from 45 054 individuals, collected from the French Health, Health Care and Insurance Survey between 2002 and 2014, a Markov model was developed to predict the future burden of alcohol consumption ≥ 20 g/day. This estimated the incidence of alcohol intake with an intermediate (20–50 g/day) or high (≥ 50 g/day) risk of cirrhosis. The impact of five primary or secondary interventions was evaluated between 2024 and 2030.

Results: A 1 L increase in per capita alcohol consumption was associated with a 7% increase in the risk of progression to 20–50 g/day and to ≥ 50 g/day (HR = 1.07, 95% CI 1.06–1.07). Female gender was associated with a lower risk (HR = 0.47, 95% CI 0.43–0.51) and age < 45 years with a higher risk (HR = 4.15, 95% CI 2.60–6.63) of consuming ≥ 50 g/day. In 2023, 2.5 million French individuals aged 15–74 years old drank ≥ 20 g/day (5.5%), and 435 000 of these drank ≥ 50 g/day. Based on the status quo (SQ), this prevalence would be 5.1% in 2030, and would not be influenced by primary prevention, but would be reduced by secondary interventions (from −2.0% to −13.7% compared to the SQ depending on the rate of implementation).

Conclusions: Primary interventions are important to reduce the overall impact of alcohol on health. The strategy of targeting individuals who already drink ≥ 20 g/day of alcohol is more effective in reducing the short-term burden of alcohol consumption at risk of cirrhosis than primary interventions. Thus, primary and secondary interventions need to be implemented jointly.

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Summary

- Our model shows the burden of individuals with alcohol consumption at risk of cirrhosis.
- It could be an interesting tool for public health decision-makers to identify the most effective policies to reduce this burden.
- It shows that primary prevention is not sufficient and emphasises the need for secondary prevention in populations that are at risk of cirrhosis.

1 | Introduction

In France, alcohol abuse is a major public health issue with 41 000 alcohol-related deaths in 2015. Cirrhosis, alone or in association with hepatocellular carcinoma (HCC), is the main cause of these alcohol-related deaths (around 11 700 deaths—28.4%). Non-liver cancers and cardiovascular diseases, responsible for 11 000 and 9900 deaths respectively, are the next leading causes of alcohol-related death [1]. There is a continuous dose–response association between the amount of alcohol consumed and the risk of cirrhosis. With more than 20 g of alcohol per day (g/day), compared to lifetime non-drinkers, the risk of cirrhosis is around doubled and increases exponentially in individuals who drink ≥ 50 g/day (RR ~ 5) [2, 3]. The percentage of individuals who drink 20–50 g/day or ≥ 50 g/day varies according to gender, age, socio-economic factors, and cultural environment [4]. Further knowledge is still needed to understand the kinetics of beginning to consume a quantity of alcohol that is at risk of cirrhosis and to determine whether the kinetics differ between the thresholds of 20 and 50 g/day. This could help develop optimal prevention strategies.

Even if the overall per capita alcohol consumption has steadily decreased for several decades in France, alcohol consumption remains among the 4th highest in Europe, at 11.6 L in 2018. This value is close to that observed in Lithuania (11.4 L), the Czech Republic (11.8 L) and Austria (12.1 L). In the European Union, the range of per capita alcohol consumption varied from 6.0 L in Greece to 13.0 L in Latvia [5]. However, although daily alcohol consumption is decreasing among French individuals over 35–40 years old, there has been a significant increase in binge drinking among young people [6]. It has been established that repeated episodes of binge drinking during adolescence are a risk factor for becoming a drinker with a risk of cirrhosis during adulthood [7–9].

Current data are available on per capita alcohol consumption, the prevalence of individuals consuming any amount of alcohol, the prevalence of individuals that consume alcohol daily or intermittently, and the frequency of episodes of binge drinking. It is important to estimate the transition between these different behaviours depending on host variables and time. This could help predict the epidemiological progression of individuals who consume amounts that are at risk of cirrhosis. This is the only way to predict the effects of public health policies on the prevalence of alcohol consumption at risk of cirrhosis and to evaluate innovative strategies to target this population.

There is strong evidence that public health policies such as prohibition, alcohol pricing and taxation, availability, marketing, and labelling reduce per capita alcohol consumption [10–15]. However, the extent of their effect in relation to different drinking patterns requires further study. Among these primary policies, although prohibition was effective in Russia, the US and Canada, this effect was not sustained because it was a socially unpopular and inacceptable option [13–15]. To attain the objective of reducing the number of individuals with risky drinking behaviours, experts propose screening and brief behavioural counselling as a secondary intervention approach [10, 16, 17]. However, the impact of secondary interventions on reducing per capita alcohol consumption needs to be explored in a population-based study.

Mathematical models provide a conceptual framework to predict disease progression and its consequences on public health, and to determine the extent that parameters need to be modified to limit this process. In particular, the Markov model estimates past and future incidences, trends over time as well as their relationship to age and sex, which are essential indicators to understand the consumption of alcohol at risk of cirrhosis [18, 19]. Thus, we used the French Health, Healthcare and Insurance Survey (ESPS), a large database of 45 000 individuals with data on alcohol consumption over time, to develop a Markov model. This model can provide insight into the short and intermediate term impact of primary and secondary interventions on the incidence and prevalence of alcohol consumption at risk of cirrhosis.

The present study 1/describes how the model was designed to quantify the incidence of alcohol consumption at risk of cirrhosis in the general population, 2/predicts its future burden, and 3/identifies and estimates how public health policies can influence this burden in the population at the highest risk of developing cirrhosis.

2 | Materials and Methods

2.1 | Overview

This modelling study traced and predicted the prevalence of binge-drinking in 15–24-year-olds, drinking alcohol at risk of cirrhosis (≥ 20 g/day) in 15–74-years-old over time, as well as evaluating the future burden of the latter depending on different prevention strategies.

2.2 | Model Structure (Figure 1)

We designed a Markov model, with four alcohol consumption patterns (see Data S1 for mathematical considerations):

- Stage 1, < 20 g/day;
- Stage 2, binge-drinking in young people under the age of 25, defined as the consumption of ≥ 6 standard drinks in one sitting;

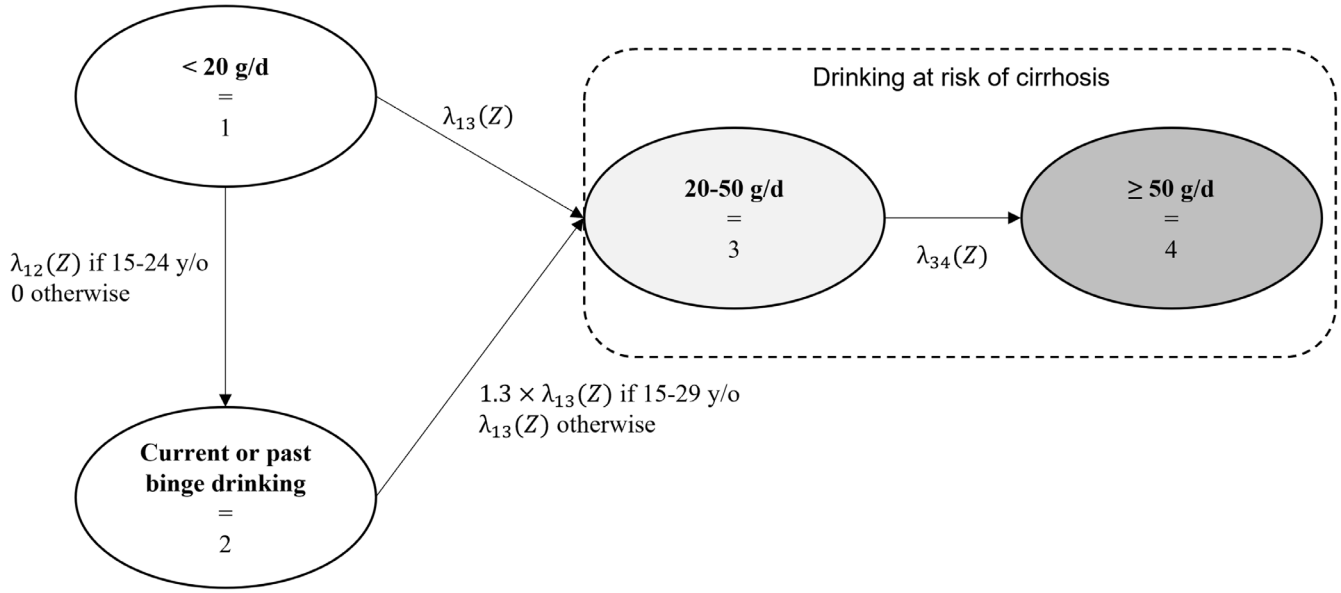


FIGURE 1 | Markov model of alcohol patterns. Direct transitions can occur from one stage to the next indicated by an arrow while no direct transitions are allowed from stage 1 to stage 4 or from stage 2 to stage 4. $\lambda_{ij}(Z)$ are the transition rates between stage i and stage j, where Z is the vector of covariates (sex, age, per capita alcohol consumption, calendar year), depending on the considered transition. Although the structure of the model indicates only ascending transitions between alcohol patterns but also integrates regression, $\lambda_{ij}(Z)$ being an average between progression and regression transitions.

- Stage 3, 20–50 g/day (intermediate risk);
- Stage 4, ≥ 50 g/day (high risk).

Although the structure of the model indicates only ascending transitions between alcohol patterns, it also integrates regression and the estimated parameters are an average between progression and regression transitions.

2.3 | Data

The 16–64-year-old individuals who answered the biannual French Health, Health Care and Insurance Survey (ESPS) between 2002 and 2014 were eligible for this study ($n = 65\,284$) [20]. ESPS is designed to represent 97% of the French metropolitan population and respondents are selected among the beneficiaries of French health insurance [20].

We selected individuals who answered the three self-reporting Alcohol Use Disorders Identification Test-C (AUDIT-C) questions corresponding to 45 054 respondents. Details concerning daily alcohol intake calculation and flow charts are provided in Data and Figure S1, respectively.

2.4 | Covariates

We incorporated two available covariates into the model that were likely to be associated with the progression to drinking at risk of cirrhosis: sex and age in years considered in two classes ± 45 years old, the most discriminant age cut-off in our study population. We also took into account changes in alcohol consumption behaviours over time with a temporal variable not included in the questionnaires (see Data S1 and Figure S2 for details):

- "per capita alcohol consumption" for the entry into drinking at an intermediate (20–50 g/day) or high (≥ 50 g/day) risk of cirrhosis.
- "calendar year" for beginning binge-drinking in 15–24-years-old.

2.5 | Procedure

There were three steps to this study.

First, the model was designed and calibrated to ESPS data to estimate transition rates between the four alcohol consumption patterns and the effect of covariates on these transition rates. Grid-searching was performed to determine the incidence of binge drinking (from stage 1–2) in 15–24-years-old individuals, and the effect of sex and calendar year on this transition [6]. Consequently, the incidence was 6% in15–24-year old men before 1990, increasing to 7% per year between 1990 and 2005 (HR = 1.07 vs. the period < 1990) and was 60%-lower in women (HR = 0.4 vs. men). All the other model parameters were estimated by maximum likelihood methods. Model calibration was assessed by comparing the predicted and the observed alcohol pattern of ESPS respondents. To reduce the number of estimated parameters and based on the literature [7, 9], we considered that binge drinkers (stage 2) have a 1.3 times higher risk of intermediate drinking (20–50 g/day, stage 3) than drinkers who consumed < 20 g/day of alcohol (stage 1) until the age of 30, and thereafter the same risk.

Once parameters were estimated, the second step simulated the different patterns of alcohol consumption in all 15-year-old cohorts from 1900 to the present or up to age 100 (to cover all age cohorts in the ESPS data), whichever came first, taking into account the risk of overall mortality which is explained in the Data S1. As a result, we obtained the prevalence of the different alcohol patterns over time for 15–74-year-old.

Finally, the model was used to predict the burden, in relation to the prevalence and cumulative numbers of individuals drinking at risk of cirrhosis up to 2030. The cumulative number was defined as the sum over 2024-considered years (between 2024 and 2030) of individuals who changed alcohol consumption patterns in a given year. Two types of actions were taken from 2024 to 2030, and the impact of the five resulting hypothetical health policy strategies was evaluated in 2030:

- Status quo strategy: the annual per capita alcohol consumption continues to slowly decline and would be 10.6 L in 2030 (Figure S2).
- Strategy 1 (S1): primary prevention, that is, an action uniformly targeting all individuals in the general population. In our context, this action aims to accentuate the decrease of annual per capita alcohol consumption to reach 10.0 L in 2030, which is a symbolic level that border countries of France have reached and the average level in the 27 EU countries [5].
- Strategy 2 to Strategy 5 (S2–S5): secondary prevention, that is, an action targeting subgroup(s) of individuals already at risk. In our context, the goal of this action is to decrease alcohol consumption in drinkers who are already at risk of cirrhosis (≥ 20 g/day) using behavioural interventions and different levels of implementation. The effectiveness of any strategy is equal to the efficacy of an intervention multiplied by the probability of receiving this intervention (i.e., level of implementation). As a consequence, in our model:
  - Efficacy: Based on the literature, we assumed that 15% of intermediate-risk drinkers (20–50 g/day) had a sustainable reduction in their alcohol consumption and became low-risk drinkers (< 20 g/day). In the subgroup of high-risk drinkers (≥ 50 g/day), we assumed that 10% became intermediate-risk drinkers (20–50 g/day) and 2% became low-risk drinkers (< 20 g/day) [21–25].
  - Probability of receiving one intervention (level of implementation): We hypothesised that between 20% (S2) and 80% (S5) of existing at-risk drinkers will receive at least one behavioural intervention during the 2024–2030 period, corresponding to between 3.1% and 20.5% per year. This goal can be achieved since 80% of the French are seen by a medical doctor at least once a year [26].
  - The effectiveness associated to S2–S5 in the model are provided in Table S1. For example, between 2024 and 2030, if 20% had a behavioural intervention during the period (equal to 3.1% per year) (S2), the 20–50 g/day drinkers had a 0.47% (15% × 3.1%) annual probability of becoming < 20 g/day drinkers while ≥ 50 g/day drinkers had a 0.31% (10% × 3.1%) annual probability of becoming 20–50 g/day drinkers and 0.06% (2% × 3.1%) of becoming < 20 g/day drinkers.

2.6 | Statistical Analysis

Analyses were performed with the statistical software R using the msm analysis routine.

3 | Results

3.1 | Characteristics of the ESPS Survey Participants

The characteristics of the 45 054 participants from the ESPS surveys are summarised in Table 1. Mean age was 40.2 (standard deviation, 13.6 years) and 48.5% were males. Drinking at risk of cirrhosis (≥ 20 g/day) was found in 2325 (5.2%) of these individuals, including 503 (1.1% of the total cohort) high-risk drinkers (≥ 50 g/day).

3.2 | Model Fit

The model satisfactorily predicted the observed alcohol patterns reported in the ESPS data (Table 2), with a global error of 2.6%

TABLE 1 | Characteristics of the respondents of the French Health, Health Care and Insurance Survey (ESPS) respondents.

	Respondents
Number of individuals	45 054
Male (%)	21 856 (48.5)
Age at survey, mean (SD), years	40.2 (13.6)
16–24 years old	8057 (17.9)
25–29 years old	3672 (8.2)
30–44 years old	14 536 (32.2)
45–64 years old	18 789 (41.7)
Alcohol pattern at survey (%)	
< 20 g/day	40 200 (89.2)
Binge drinking [only 16–24 years old]	2529 (5.6)
Drinking at risk of cirrhosis	2325 (5.2)
Intermediate: 20–50 g/day	1822 (4.0)
High: ≥ 50 g/day	503 (1.1)

Abbreviation: SD, standard deviation.

TABLE 2 | Adequacy of alcohol patterns between observed in five surveys and predicted by the model ($n = 45\,054$).

	Observed	Predicted
< 20 g/day	40 200	39 616
Binge drinking	2529	2935
20–50 g/day	1822	1993
≥ 50 g/day	503	510

(1168 incorrect classifications/45 054 included participants). For example, it predicted 39 616 (vs. 40 200 observed) non-drinkers or drinkers who drank less than 20 g/day, and 510 drinkers (vs. 503 observed) at high risk of cirrhosis (≥ 50 g/day).

3.3 | Parameter Estimates

Table 3 reports the estimated baseline transition rates from stage *i* to stage *j*, λ_{ij} (and their 95% confidence intervals (CI)) that correspond to men aged ≥ 45 years and an annual per capita alcohol consumption equal to 11.8 L (2014 value in France). These transition rates can be expressed as the number of annual transitions from stage *i* to stage *j*. For example, the baseline $\lambda_{13} = 0.26\%$ means that 26 out of 10 000 men aged ≥ 45 years with daily alcohol intake lower than 20 g/day will progress to intermediate drinking (20–50 g/day) in 1 year.

Concerning the independent effect of each incorporated covariate, women were found to have a lower risk of progression than men, with a transition risk to 20–50 g/day that was 87% lower (HR = 0.13, 95% CI 0.13–0.14) and a risk of transition to ≥ 50 g/day that was 53% lower (HR = 0.47, 95% CI 0.43–0.51).

Compared to individuals older than 45, individuals younger than 45 have a higher risk of beginning to consume 20–50 g/day alcohol (HR = 1.13, 95% CI 0.98–1.29) and a higher risk of transition from 20 to 50 g/day to ≥ 50 g/day (HR = 4.15, 95% CI 2.60–6.63).

A 1 L decrease in per capita alcohol consumption was associated with a 7% decrease in the risk of progression to 20–50 g/day and to ≥ 50 g/day (HR = 1.07, 95% CI 1.06–1.07) and must be calculated in relation to the 2014 value in France, 11.8 L. For example, a 4 L decrease in per capita alcohol consumption was associated with a 31% decrease in the risk of progression (i.e., $1.07^{15.8-11.8} = 1.31$). This decrease was observed in France between 1994 (15.8 L) and 2014 (11.8 L).

3.4 | Past and Current Prevalence of Binge Drinking and Drinking at Risk of Cirrhosis

Figure 2 describes past and present annual per capita alcohol consumption and the different alcohol consumption patterns in the 15–74 years old general population in France. It is interesting to note that the slope of the decrease in drinking at risk of cirrhosis in 15–74-year-old (Figure 2B) is similar to that of per capita alcohol consumption (Figure 2A). The model estimated that between 1960 and 2014, the decrease in the prevalence of high-risk drinking (≥ 50 g/day, −58%) was more marked than in 20–50 g/day (−29%), compared to a 54%-decrease for per capita alcohol consumption (Figure 2B). The prevalence of binge drinking in 15–24-years-old increased significantly and has remained stable at around 35.5% since 2010 (Figure 2C).

In 2023, the model predicted that the prevalence of drinking at risk of cirrhosis was 5.5% in 15–74-years-old, corresponding to 2.5 million individuals. Among them, around 435 000 individuals were high-risk drinkers (≥ 50 g/day), representing 1.0% of the general population (Figure 3). Most drinkers at risk of cirrhosis (≥ 20 g/day) were men: 8 out of 10. Moreover, Figure 3 shows that this prevalence increased with age, from 1.8% in

TABLE 3 | Baseline transition rates (λ_{ij}) and hazard ratios of the covariates Z impacting these baseline transition rates with their respective 95% confidence interval (95% CI).

	Parameter estimates (95% CI)
Baseline transition rates[a] λ_{ij}	
λ_{13}: < 20 g/day → 20–50 g/day	0.26% (0.23%–0.30%)
λ_{34}: 20–50 g/day → ≥ 50 g/day	0.32% (0.20%–0.51%)
Hazard covariate effects	
< 20 g/day → 20–50 g/day	
HR women	0.13 (0.13–0.14)
HR 15–44 years old (ref: 45–64 years old)	1.13 (0.98–1.29)
HR annual per capita (ref: 11.8 L)	1.07 (1.06–1.07)
20–50 g/day → ≥ 50 g/day	
HR women	0.47 (0.43–0.51)
HR 15–44 years old (ref: 45–64 years old)	4.15 (2.60–6.63)
HR annual per capita (ref: 11.8 L)	1.07 (1.06–1.07)
Grid searching results: binge drinking (15–24 years old only)	
λ_{12} for men, before 1990	6%
HR women	0.40
HR annual increase between 1990 and 2005	1.07

[a]Baseline λ_{ij} values correspond to transition rates between stage *i* and *j* for men aged ≥ 45 years old for per capita alcohol consumption equal to 11.8 L (2014 in France).

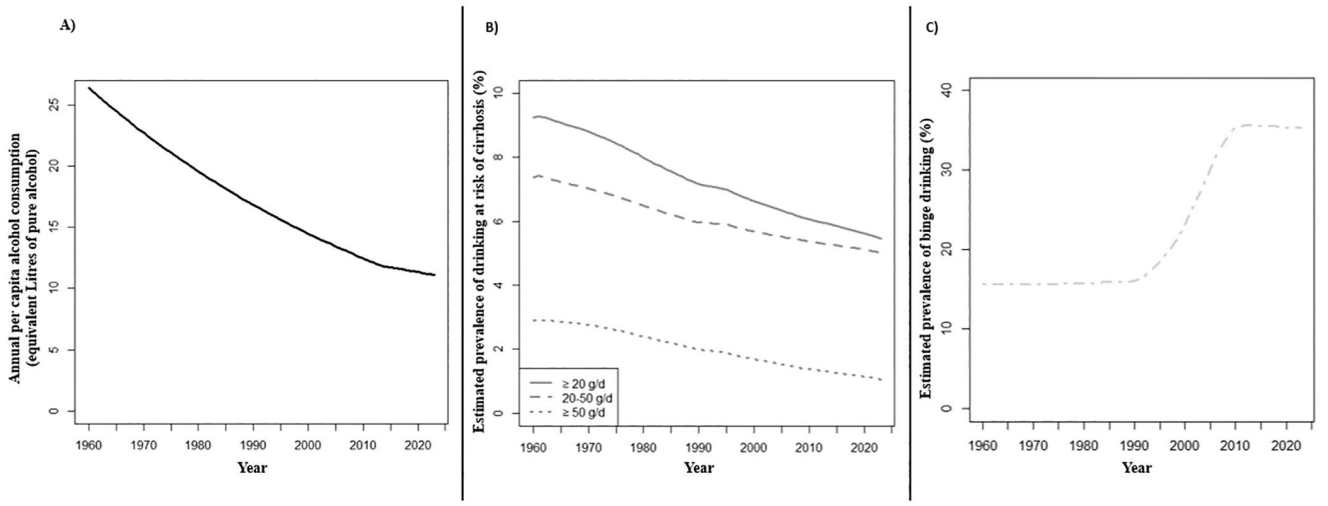


FIGURE 2 | Progression of (A) annual per capita alcohol consumption, (B) drinking at risk of cirrhosis (≥20 g/day) in 15–74 years old and (C) binge-drinking in15–24-year-old, in France between 1960 and 2023. Annual per capita alcohol consumption estimations were obtained from the French Observatory of Drugs and Addiction while estimated prevalences were calculated from the estimated model parameters.

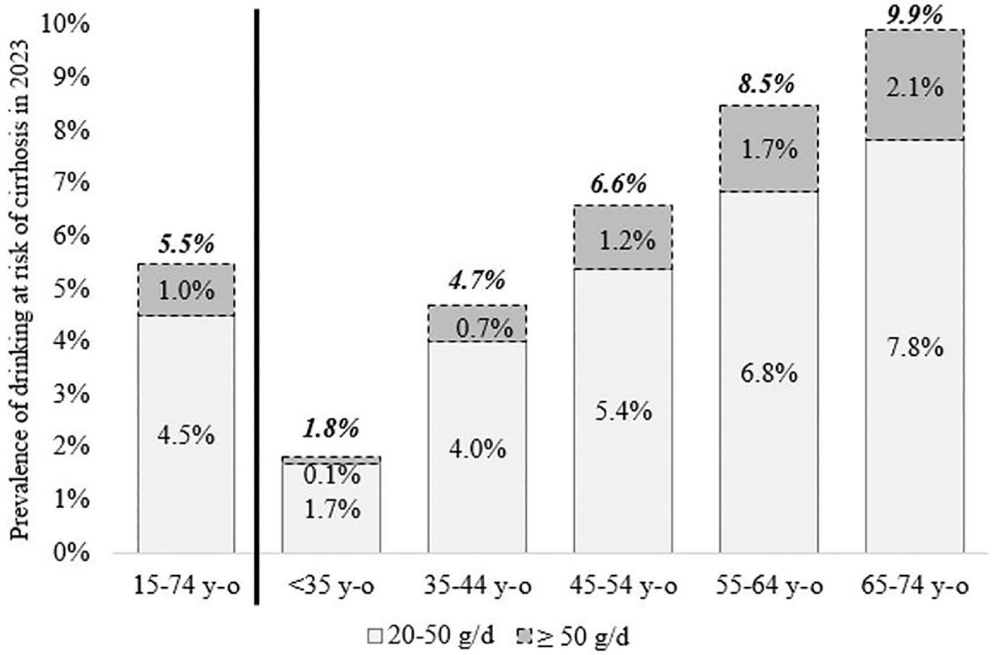


FIGURE 3 | Estimated prevalence of drinking at risk of cirrhosis (≥20 g/day) in 15–74 years old in 2023 according to age and alcohol intake.

those under 35 years old to 9.9% in the 65–74 years old, corresponding to a prevalence that was 5.5 times greater than in the youngest (< 35) group. In the subgroup of high-risk drinkers, this difference was even more marked since 65–74-years-old had a 21-fold greater prevalence than < 35 years old (2.1% vs. 0.1%).

3.5 | Impact of Different Strategies on Future New Drinkers at Risk of Cirrhosis

As mentioned above, the prevalence of drinking at risk of cirrhosis in 15–74-years-old was 5.5% in 2023. If no changes are made (Status quo strategy), this prevalence will be 5.1% in 2030 (Figure 4), and annual per capita alcohol consumption will be 10.6 L.

On one hand, S1, whose aim is to decrease annual per capita alcohol consumption to 10.0 L in 2030, had no impact on the prevalence of drinking at risk of cirrhosis in 2030 (Figure 4). On the other hand, secondary prevention with behavioural interventions (S2–S5) targeting drinkers at risk of cirrhosis did influence the prevalence in 2030, and the greater the number of interventions, the greater the influence. The prevalence of drinking at risk of cirrhosis would decrease to 5.0% (S2), 4.8% (S3), 4.6% (S4), and 4.4% (S5), that is, a decrease between −2.0% (S2) and −13.7% (S5) compared to the Status quo (Figure 4).

To further understand the results of these different strategies, we analysed the cumulative numbers of individuals that changed alcohol consumption patterns between 2024 and 2030. Between 2024 and 2030, the cumulative number of intermediate-risk (20–50 g/day) and high-risk (≥ 50 g/day) drinkers will be 409 400 and 63 400, respectively, if no changes are made (Status quo strategy, per capita 10.6 L in 2030) (Table S2). S1, whose aim is to decrease per capita alcohol consumption to 10.0 L in 2030, could result in a decrease in the number of individuals switching to intermediate (20–50 g/day) and high (≥ 50 g/day) risk alcohol consumption of 2.3% and 2.4%, respectively, corresponding to around 400 100 and 61 800 individuals between 2024 and 2030 (Figure 5A and

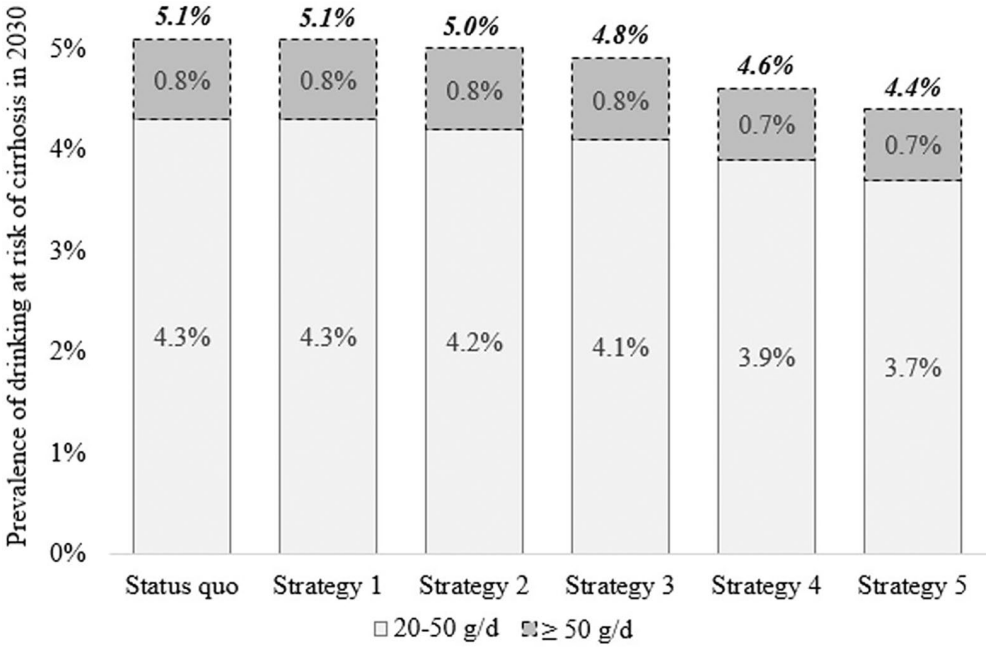
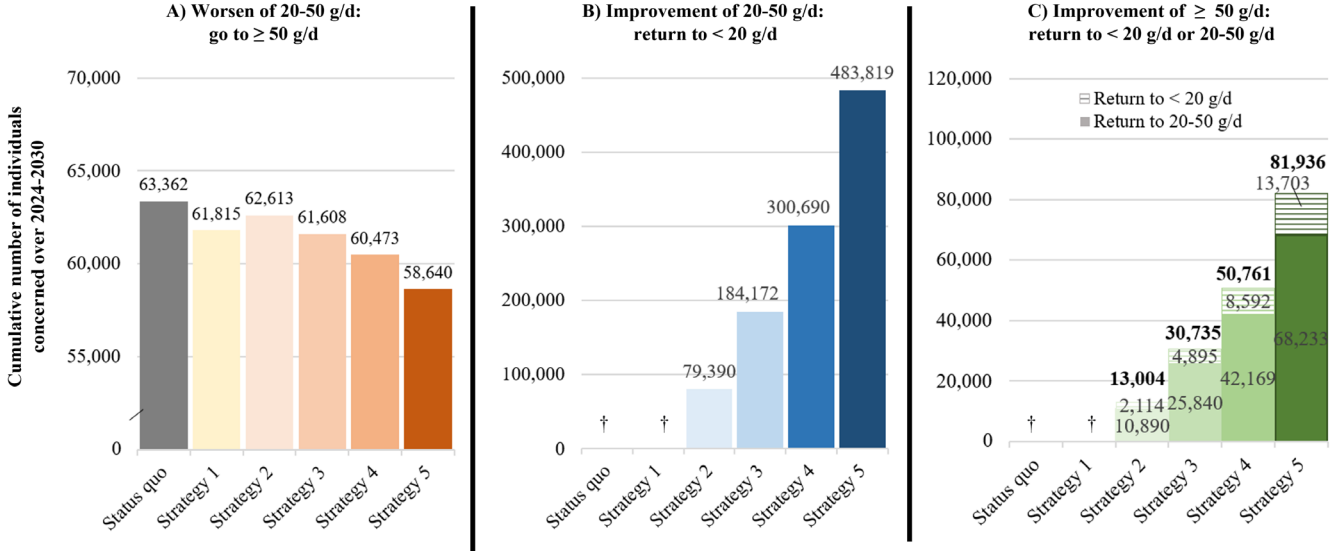


FIGURE 4 | Estimated prevalence of drinking at risk of cirrhosis (≥ 20 g/day) in 15–74 years old in 2030 according to Status quo and strategies S1–S5, and alcohol intake.



† *Status quo and Strategy 1 are not defined to specifically decrease the level of alcohol consumption in individuals who already drink ≥ 20 g/d. As a consequence, the number of individuals reducing their level of consumption cannot be quantified for them.*

Status quo: the annual per capita alcohol consumption continues to slowly decline (10.0 L in 2030)
Strategy 1: primary prevention aiming to accentuate the decrease of per capita alcohol consumption (10.6 L in 2030)
Strategy 2-5: secondary prevention aiming to decrease alcohol consumption in drinkers who are already at risk of cirrhosis (≥ 20 g/d) using behavioural interventions and different levels of implementation (20% to 80%)

FIGURE 5 | Cumulative number of individuals with an alcohol consumption at risk of cirrhosis who worsen (A) or improve (B, C) their alcohol consumption over 2024–2030 according to Status quo and strategies S1–S5.

Table S2). In addition, secondary prevention with behavioural interventions (S2–S5) targeting drinkers at risk of cirrhosis is by definition not designed to influence the cumulative number of 20–50 g/day drinkers and thus would only influence the cumulative number of intermediate-risk drinkers switching to high-risk drinkers (≥ 50 g/day), with higher impact in the most implemented strategy (S5) (Figure 5A and Table S2).

Finally, with a secondary prevention strategy implemented at 20% (S2), 79 400 intermediate risk drinkers will become < 20 g/day drinkers (Figure 5B and Table S2) and 13 000 high-risk drinkers will become intermediate risk drinkers (10 900) or < 20 g/day drinkers (2100) (Figure 5C and Table S2), corresponding to 1 out of 25 individuals who currently drink 20–50 g/day alcohol and 1 out of 33 who currently drink ≥ 50 g/day of alcohol. Logically, these proportions would increase if there were more secondary prevention actions (S3–S5) (Figure 5B,C) and reach 1 out of 4 who drink 20–50 g/day alcohol and 1 out of 5.5 who drink ≥ 50 g/day with the most ambitious strategy (S5).

4 | Discussion

This study provides a Markov model that estimates the past and future progression of alcohol consumption in France. The prevalence of individuals drinking ≥ 20 g/day and thus at risk of cirrhosis decreased from 9.2% in the 1960s to 5.5% in 2023 which corresponds to the decrease in per capita alcohol consumption in France. In 2023 this corresponds to around 2.5 million individuals, 8 out of 10 men. The prevalence of the population that drinks ≥ 20 g/day has increased with age with the highest prevalence in individuals aged 65–74 years old. The model showed a steady increase in binge drinking in 15–24-years-old until 2010. The model predicts that binge drinking will remain stable at 35.5% and alcohol consumption ≥ 20 g/day at 5.1% in 2030. As expected, primary prevention strategies will not affect the short-term prevalence of people drinking ≥ 20 g/day. On the other hand, our model predicts that a secondary prevention strategy with brief interventions would decrease this prevalence by at least 2.0% in 2030.

Understanding the dynamics of the burden of alcohol consumption at risk of cirrhosis is a complex issue that can be evaluated by modelling. This approach highlights contributing cofactors such as sex, age, calendar year, and per capita alcohol consumption. This information can be used to develop optimal public health policies that integrate these factors and more specifically define which measures are needed. In particular, although prohibition has been shown to be an effective policy to decrease alcohol-related mortality [13–15], it is a socially unpopular and unacceptable option; thus, the development of sustainable and innovative strategies is needed.

Our model confirms and quantifies the effect of per capita alcohol consumption on the incidence and prevalence of drinkers ≥ 20 g/day. It predicts that if the per capita alcohol consumption continues to decline at the same rate as in previous years (−0.08 L/year since 2015), its impact will be marginal. Even a public health policy that results in France attaining the average per capita alcohol consumption of the 27 EU countries (10.0 L in 2018) in 2030 will have little impact on the number of individuals who consume ≥ 20 g/day. This suggests that a decrease in per capita alcohol consumption is not sufficient in itself and supports the development of alternative strategies.

Binge drinking, a phenomenon that has developed in the last two decades among young people, is a major public health issue. Data from the French Survey Baromètre Santé on binge drinking in the young shows that, after steadily increasing, its prevalence stabilised around 2010 [6]. The explanation for this plateau is unclear and could be linked to either reaching a maximum threshold or to a change in behaviour thanks to warnings from the health authorities. The dissociation between the progression of per capita alcohol consumption and binge drinking shows that specific public health policies are needed to target this phenomenon. The aim of these policies should be to reduce not only the incidence of binge drinking but also the number of episodes and the amount of alcohol ingested per episode.

Our model explores different indicators such as the prevalence of drinking at risk of cirrhosis or the cumulative number of individuals drinking at risk of cirrhosis, which show the impact of strategies on primary and secondary prevention. Our model shows that primary interventions can cause a slight decrease in the prevalence of alcohol consumption at risk of cirrhosis in a short time. On the other hand, secondary interventions will have a greater impact on individuals who already consume amounts at risk of cirrhosis. Our approach provides quantitative data to integrate the interplay between primary and secondary preventions. It also suggests that different endpoints are needed, such as decreasing the prevalence of drinkers ≥ 50 g/day and preventing the increase of new drinkers in each class of alcohol consumption. In France, for example, 80% of adults visit their general practitioner (GP) at least once a year, but less than half of GPs use standardised tools to screen potentially at-risk patients [26]. Thus, if a public policy could be developed to convince GPs to perform a brief intervention, this simple action could reduce both the prevalence and incidence of alcohol consumption at risk of cirrhosis [26, 27]. An innovative public health policy to increase brief interventions would require a plan to inform and educate GPs through workshops, post-graduate seminars, and courses associated with scientific events, as well as training for young doctors. Brief interventions could also be performed by other healthcare practitioners.

This study has certain limitations. First, the model was based on self-reported alcohol consumption data, which may underevaluate participants' drinking. Also, our data may have underestimated the global effect of secondary intervention on the extra-hepatic events that may represent an important burden. Indeed, the thresholds of alcohol intake at risk for extra-hepatic events are less known than those established in liver disease and cannot be estimated with the same approach. However, all tested strategies were affected in the same way, and it does not affect the main conclusion. Second, participants were only questioned once. Thus, we were unable to explain cessation or reduction in alcohol consumption, and we estimated the average pattern of moving back and forth through the different stages of alcohol consumption. Although fluctuations in alcohol consumption patterns are frequent [28–31], as mentioned in the Methods section, only a minority of people stop or reduce their alcohol consumption over the long term [22, 23]. Alcohol consumption is approximate in all studies and represents an average daily consumption

during a specific period. This bias suggests that new tools are needed to prospectively estimate alcohol consumption and better understand these fluctuations. Third, participants over the age of 65 were not included in the step that estimated the model parameters. Indeed, we considered that participants over 65 years old are not sufficiently representative of a lifetime of exposure to alcohol since liver-related mortality is significant during this period, especially in heavy drinkers, who could not respond to the survey. The sensitivity analysis showed that estimated parameters were not significantly different when 65–74-years-old were included in the estimation step (data not shown). The main conclusion is not affected by this restriction in the estimation process. Finally, our model integrates the progression of binge drinking compared to regular drinking although it was not developed to evaluate interventions devoted to this phenomenon.

In conclusion, the present study provides new information to help healthcare policy makers develop and evaluate their strategies to improve the future burden of alcohol consumption at risk of cirrhosis. These results suggest that innovative strategies targeting secondary interventions are needed to obtain short- and medium-term improvement.

Author Contributions

Claire Delacôte, Philippe Mathurin, and Sylvie Deuffic-Burban conceptualised the study. Claire Delacôte, Line Carolle Ntandja Wandji, Alexandre Louvet, Pierre Bauvin, Philippe Mathurin, and Sylvie Deuffic-Burban did data curation. Claire Delacôte and Pierre Bauvin did the statistical and mathematical analysis of the study data. Claire Delacôte, Line Carolle Ntandja Wandji, Alexandre Louvet, Pierre Bauvin, Philippe Mathurin, and Sylvie Deuffic-Burban interpreted and validated the results. Claire Delacôte, Philippe Mathurin, and Sylvie Deuffic-Burban wrote the original draft of the manuscript. Philippe Mathurin and Sylvie Deuffic-Burban did project administration. All authors have seen and approved the final text. All authors had full access to the data and had final responsibility for the decision to submit for publication. Claire Delacôte and Pierre Bauvin directly accessed and verified the data.

Ethics Statement

The authors have nothing to report.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The datasets generated or analysed during the current study are not available to the public because they are subject to national data protection laws and restrictions imposed by the ethics committee to ensure privacy of the study participants' data. However, access to the datasets can be applied for through an individual project agreement to IRDES (French Institute for Research and Information in Health Economics), the owner of the data, at diffusion.adisp@cnrs.fr (application number: 16977).

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.