A roadmap to ALS prevention: strategies and priorities

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INTRODUCTION
Amyotrophic lateral sclerosis (ALS) is often considered a relatively rare disease, but risk estimates suggest that the lifetime risk of ALS is 1:263 for males and 1:417 for females by age 85.1 Therapeutic efforts to date have failed to meaningfully slow disease progression or prolong survival. This may, at least in part, reflect that treatment is typically initiated late in the disease process, when damage may already be too advanced to reverse. Indeed, some evidence suggests that earlier treatment may yield better outcomes.2-3 These observations prompt a reassessment of potential approaches for treating ALS, with a shift towards a proactive strategy for preventing ALS.4

Achieving the ambitious goal of preventing ALS requires a large body of knowledge, including an understanding of the causes and risk factors for ALS. It also requires identifying a window of opportunity to study those at risk for disease, methods for predicting when the clinical manifestations of ALS will emerge, and viable strategies to intervene by mitigating risk or treating the underlying biology of disease before clinically manifest ALS emerges. Significant progress has already been made in a small subset of the population, which is at markedly elevated genetic risk for ALS by harbouring highly penetrant ALS-causing gene mutations. When the cause of disease is known, for example, genetic cause, it is possible to identify and study presymptomatic gene mutation carriers.5 Moreover, biomarkers, notably, neurofilament light chain (NFL), have been identified that predict the risk of imminent phenocconversion,6-9 and experimental therapeutics that target the underlying cause of disease have begun to emerge.8-9

This confluence of factors has facilitated the launch of the first-ever ALS prevention trial (NCT04856982) of a genetic therapy, tofersen, in carriers of highly penetrant SOD1 mutations, which are associated with rapidly progressive ALS.10 In this study, NFL levels are monitored monthly, and eligible presymptomatic people randomised to receive tofersen (an SOD1 antisense oligonucleotide) or placebo when NFL levels rise above a predefined threshold. The goal of the trial is to delay, or possibly even prevent, the emergence of clinically manifest ALS.

Preventing ALS is substantially more challenging when the cause of disease is unknown. Although it is generally accepted that genetic background, cumulative environmental exposure and advancing age combine to cause ALS,11-12 less is known about the non-genetic factors that contribute to ALS. The magnitude of the challenge may seem overwhelming in the general population given its size (~350 million in the USA alone) and the low annual incidence of disease (~2 per 100 000 persons).13 However, several innovative strategies have yielded insights, including large-scale genetic studies,14 Mendelian randomisation studies, epidemiological analyses15 and epigenetic studies.16

Notwithstanding the challenges, it is possible to identify populations at greater risk for ALS than the general population, although at much lower risk than populations harbouring highly penetrant ALS-causing gene variants. Recognising at-risk populations yields opportunities to work towards disease prevention. Also, the risk of disease for individuals carrying disease-causing genetic variants may increase in the context of particular environmental exposures.17 Therefore, the appropriate prevention strategy for higher risk groups will vary based on multiple factors spanning population size, annual risk of disease, current knowledge base and the feasibility of the relevant research approach. Below, we identify some potential groups that could be prioritised for further prevention research.

HIGHER-RISK GROUPS FOR STUDY AND TARGETING OF PREVENTION EFFORTS
People with genetic risk factors
Genetic risk factors for ALS broadly fall into three groups: (1) those that increase risk by a few percent, but because they are relatively common in the population, might represent a considerable risk in a person harbouring multiple such variants (eg, UNC13A single nucleotide variants); (2) those that increase risk more dramatically, by a few-fold (perhaps up to 300%), but are not sufficient to definitively cause disease (so-called reduced penetrance variants, eg, ATXN2 intermediate repeat expansions) and (3) those that dramatically elevate risk and are frequently associated with familial disease (eg, rare variants in the SOD1 gene). Most of these variants show age-dependent penetrance, meaning that the risk of developing ALS increases with age. The approach to studying presymptomatic disease to potentially prevent ALS has been well described for people carrying high-risk genetic variants.9 However, understanding presymptomatic ALS to contemplate preventing ALS is more challenging in the first two populations, that is, those with...
any risk factor responsible for triggering both FTD and ALS, 

nise, of course, that it may already be too late to intervene on 

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dementia (FTD), 5%–10% of whom also develop ALS.18 Since 

elevated genetic risk for ALS, are people with frontotemporal 

In addition to, and partially overlapping with, populations at 

establish new cohorts, or leverage existing population-based 

cohorts, to study both environmental risk factors for ALS, as 

as well as mild motor impairment (MMI) as a clinical syndrome 

that is prodromal to ALS. These cohorts should include 

military veterans. Formal recognition of MMI as a diagnostic 

entity, for example, by assigning a specific International 

Classification of Disease code, would facilitate such studies. 

Develop improved tools for capturing and quantifying 

environmental exposures in a scientifically rigorous 

manner that is least burdensome to ALS patients. This 
can be accomplished through direct epidemiological 

methods, as well as other approaches including Mendelian 

randomisation.42 43 44 Epigenetic studies and modelling of risk 

factors using for example, the multistep model of ALS.17 

Develop a framework for determining the level of evidence 

required to translate knowledge of an environmental 

risk factors for ALS, into a pharmaceutical, behavioural or 

ecological intervention. 

Expand efforts to study those at reduced risk for ALS, with the 
goal of identifying protective factors that could be harnessed 

for future therapeutic development.

Box 1 Research priorities to facilitate ALS prevention

⇒ Support the infrastructure needed to expand ongoing efforts, 
such as the Pre-symptomatic familial ALS (Pre-fALS) study, 
to study those at elevated genetic risk for ALS, including the 
potential interactions between genetic and environmental 
risk factors. 

⇒ Develop the infrastructure to ensure access to appropriate 
genetic counselling and testing for all ALS patients and their 
unaffected family members. 

⇒ Partner with the frontotemporal dementia and other 
neurodegenerative and neuropsychiatric communities to 
study and mitigate ALS risk among different populations at 
elevated risk for ALS. 

⇒ Establish new cohorts, or leverage existing population-based 
cohorts, to study both environmental risk factors for ALS, as 
well as mild motor impairment (MMI) as a clinical syndrome 
that is prodromal to ALS. These cohorts should include 
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⇒ Expand efforts to study those at reduced risk for ALS, with the 
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but studying this population yields an opportunity to understand 
why some people with FTD go on to develop ALS while others 
do not.

People with mild motor impairment

An until recently overlooked population at elevated risk for ALS, 
are individuals who have mild motor impairment (MMI).4 20 MMI 
represents a clinical syndrome characterised by motor symptoms 
physical signs on examination indicating upper or lower motor 
nucleus (LMN) pathology, or electromyographic (EMG) abnor-
malities indicating an underlying LMN syndrome. These symp-
toms, signs and EMG abnormalities represent a clear departure 
from normal but are not of sufficient severity or distribution to 
definitely support a diagnosis of ALS. MMI is a clinical entity 
that is non-specific but may be prodromal to ALS; it emerged 
from the study of presymptomatic gene mutation carriers. MMI 
may also occur in most people who go on to develop ALS,21 22 
Indeed, it may be possible to assemble and study a cohort of 
people with MMI, a fraction of whom will progress to develop 
ALS, but many of whom will not. Such a study could shed light 
onto the presymptomatic phase of both genetic and non-genetic 
forms of ALS, and aid in developing strategies for preventing 
progression from MMI to ALS.

Relatives of people with ALS or other or other neurological 
and psychiatric diseases

Biological relatives of people with ALS without a known family 
history of ALS have an eightfold increased risk of developing 
disease versus the general population.23 This is still a small risk 
in absolute terms but reflects shared risk factors. Biological rela-
tives of people with FTD or other neurological and psychiatric 
diseases (eg, schizophrenia) may also be at elevated risk of ALS.24 
There may be opportunities to study these populations to better 
understand the mediators of increased ALS risk. Mitigating 
these factors could represent progress towards preventing ALS. 
However, the magnitude of this challenge should not be under-
estimated since even an eightfold increased risk only translates 
into an incidence rate of 16 per 100 000 person-years follow-up, 
which is still very low.

Veterans

Similar strategies and challenges apply to studying military 
veterans whose risk of ALS (4 per 100 000 person-years) is twice 
that of the general population.25 28 Again, however, insights into 
the mediators of this increased risk may yield opportunities to 
to intervene more broadly with the goal of preventing some forms 
of ALS. Long-term population-based studies of military veterans 
may be a viable approach.

People with exposure to environmental risks

Perhaps the most significant challenge relates to the urgent need 
to identify modifiable environmental exposures that increase 
ALS risk.29 Environmental risks are implicated in most individ-
uals with non-genetic ALS,12 and even in people carrying a pene-
trant ALS genetic mutation.17 Exposures occur throughout the 
life span and across occupational,30 residential4 and avocational 
settings, making measurement of these exposures difficult. While 
progress has been made in delineating risks, such as pesticide 
exposure,31 32 lead exposure33 and physical activity,34 our under-
standing of the role of environmental factors in mediating ALS 
risk remains in its infancy. Certainly, it has not yet matured to 
an extent that would make it possible to make specific recom-
endations (eg, by reducing exposures) to meaningfully reduce
Other strategies to guide prevention efforts
Identifying and studying people at reduced risk for ALS might yield insights into factors that protect against ALS. To the extent that delineating these factors illuminates the biology or mechanism of their protective effect, they might have implications for prevention efforts. For example, an evaluation of prescription drug use in administrative health claims from US Medicare beneficiaries identified 10 drugs significantly associated with lower ALS risk, including drugs for hypertension, diabetes and cardiovascular disease.37 Additionally, tamoxifen was related to lower ALS risk and testosterone to a higher risk in females.38 This drug development strategy might also be applied to preventing ALS in appropriately high-risk groups for identified risk factors.

CONCLUSION
Because of the limited capacity of the central nervous system for repair, early treatment of ALS is preferred, before there has been significant neuronal loss. Preventing ALS takes this idea to its logical conclusion, by stopping the neuronal loss before it manifests. To this end, we have identified a series of research priorities to facilitate ALS prevention (box 1). Despite the many challenges to achieve this goal, developing appropriate studies and cohorts will accelerate progress, making ALS prevention, at least in some people, achievable in the future. Our ultimate objective is to develop interventions that can prevent ALS in people. While efforts are underway to do this in a subset of highly penetrant SOD1 mutation carriers and will need to be done for those carrying penetrant mutations in other genes, it has never been attempted on a larger scale. Success will require the ALS community to address both scientific and organisational challenges.

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