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Exploring the role of diet in reducing cancer risk in UK firefighters: Mediterranean pattern and the potential for targeted nutritional strategies

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Review Article

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Abstract

Firefighters face significantly elevated cancer risks due to chronic exposure to carcinogenic fire effluents and occupational stressors. In 2022, the World Health Organization classified firefighting as a carcinogenic occupation, linking it to increased incidences of cancers, including mesothelioma, bladder, prostate, colon and melanoma. Drawing on UK-specific data where possible, this narrative review explores how dietary strategies, particularly the Mediterranean diet, may complement existing protective measures in mitigating these risks. It investigates specific food-based nutrients that show promise in addressing risks associated with fire effluent contaminants, examining nutrient-mediated mechanisms and their relevance to firefighter health. The review also highlights the distinct combination of challenges firefighters face in adopting healthier dietary patterns, including disrupted routines, group eating cultures and gaps in nutritional education. While the evidence for firefighter-specific dietary interventions is still emerging, this review highlights the potential of sustainable dietary strategies to significantly reduce cancer risks and improve long-term health outcomes. Finally, it calls for targeted research and interventions to refine these strategies and deliver tangible health benefits for firefighters worldwide.

Introduction

Cancer remains a leading global health concern, with the UK reporting 387 820 new diagnoses in 2020, reflecting a nearly 6% increase compared with 2 years prior[1]. In 2022, the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) reclassified occupational exposure as a firefighter as 'carcinogenic to humans' (Group 1)[2], reflecting a growing body of research demonstrating a significant cancer risk among career firefighters[3].

Mesothelioma and bladder cancer have been identified by the IARC as having sufficient evidence to establish a causal link to firefighting. Suggestive evidence also connects firefighting with cancers of the colon, prostate, testis, melanoma and non-Hodgkin lymphoma. Other studies have indicated increased risks of cancers of the airway, thyroid and kidney among firefighters[4]. While some studies suggest elevated risks of breast and cervical cancers for female firefighters, the limited sample sizes make it difficult to establish definitive conclusions[5–7].

Although UK fire service data support the connection between firefighting and cancer[7,8], the Industrial Injuries Advisory Council (IIAC) currently recognises only mesothelioma as a prescriptive disease for firefighters[9].

The primary driver of the elevated cancer risk among firefighters is their exposure to contaminants contained in fire effluents[10], which include, among others, benzene, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), asbestos, arsenic, formaldehyde and heavy metals (lead, cadmium, chromium, nickel)[7,10,11]. These carcinogens contribute to cancer risk primarily through direct DNA damage but also by promoting chronic inflammation, a recognised hallmark of cancer driven by sustained immune activation, oxidative stress and tissue damage[12,13].

While the use of personal protective equipment (PPE) and cleansing methods is promoted by UK fire services and the Fire Brigade's Union, these measures do not fully eliminate exposure risks[14,15]. Certain contaminants remain in the body for years after their initial uptake[16], leaving firefighters who worked before the implementation of recent safety measures potentially at risk from previously absorbed chemicals.

However, chemical exposure is not the only occupational hazard contributing to cancer risk in firefighters. Shift work, classified as 'probably carcinogenic to humans' by the IARC, further complicates the risk profile. The disruption of circadian rhythms caused by irregular work schedules has been linked to weight gain, hormonal imbalances, reduced DNA repair efficiency and chronic inflammation – all of which can elevate cancer risk independently of chemical exposures[17]. Studies suggest that shift work increases the likelihood of developing hormone-

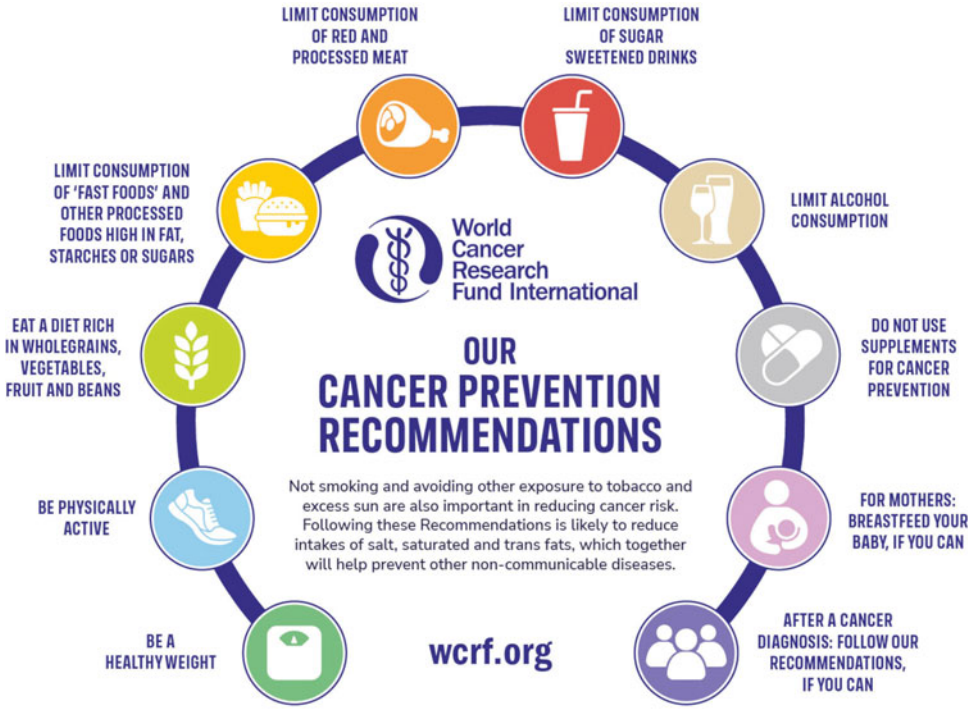

Fig. 1. WCRF cancer prevention recommendations[27]. This material has been reproduced from the World Cancer Research Fund/American Institute for Cancer Research. Diet, nutrition, physical activity and cancer: a global perspective. Continuous update project expert report 2018. Available at dietandcancerreport.org.

related cancers, such as breast and prostate cancer, as well as other malignancies associated with immune dysfunction[17–19]. This highlights the multifactorial nature of cancer risk among firefighters, where both chemical and non-chemical occupational hazards intersect.

Compounding these risks, changes to the UK firefighters' pension scheme in 2015 require firefighters to work until a later age to access full benefits. This change carries a genuine risk of increased cancer incidence, due to prolonged exposure to contaminants, coupled with the natural, age-related decline in the body's antioxidant systems, such as the glutathione cycle[20,21]. This cumulative effect underscores the importance of considering supplementary protective measures.

While contaminant avoidance remains the priority for fire services and their crews, it is vital to explore additional protective strategies, including nutrition, which is non-intrusive and scalable and has wide-reaching implications for health and cancer risk reduction.

Previous papers have provided broad overviews of the possible influences – both positive and negative – of firefighters' diet and lifestyle on cancer risk[22–24]. The current paper aims to extend this body of work by looking at specific foods and nutrients that may be bioactive against a range of firefighter chemical exposures. It also considers the unique cultural and systemic barriers faced by UK firefighters and explores potential methods for overcoming them.

The role of diet in reducing cancer risk

In addition to occupational exposures, many cancers are linked to lifestyle factors. According to a recent UK government review, four in ten cancer cases are attributable to diet and lifestyle, and up to eight in ten are considered 'preventable in principle'[25].

The World Cancer Research Fund (WCRF) lists ten key Cancer Prevention Recommendations that have been shown to reduce risk of cancer[26]. These are visually summarised in Figure 1[27].

This falls in line with the recommendations of the UK government[25], and it comes from examination of thousands of studies and meta-analyses that have explored the links between cancer and dietary and lifestyle factors.

An Italian study followed 5271 participants over 14 years and found that individuals with higher adherence to the WCRF guidelines experienced significantly lower mortality rates. For men, this included reduced risks of death from all causes, digestive system diseases and cancer. For women, high adherence was associated with lower mortality from causes other than cancer[28].

The protective effects of nutrition are largely associated with three key factors: the reduction of direct carcinogens (for example, nitrates in processed meats), the avoidance of foods that promote adiposity (for example, saturated fats and sugar-sweetened beverages) and the inclusion of protective dietary components such as dietary fibre and phytochemicals such as carotenoids, dithiothiones, isothiocyanates, flavonoids and phenols. Vegetables and fruits are also a rich source of nutrients linked to a reduced risk of cancer, such as vitamins C and E, selenium and folate. A substantial body of experimental data links many of these compounds with anti-tumorigenic effects in various cells in both animal and *in vitro* studies[29].

The exposures in Figure 2 show the WCRF summary of conclusions[30]. They were graded using a set of pre-defined criteria established by the WCRF which assess the quality and consistency of evidence across studies, the presence of plausible biological mechanisms and the strength of associations[31]. This systematic approach ensures that recommendations are based on the strongest available evidence, while areas with limited or conflicting data remain under review to guide future research.

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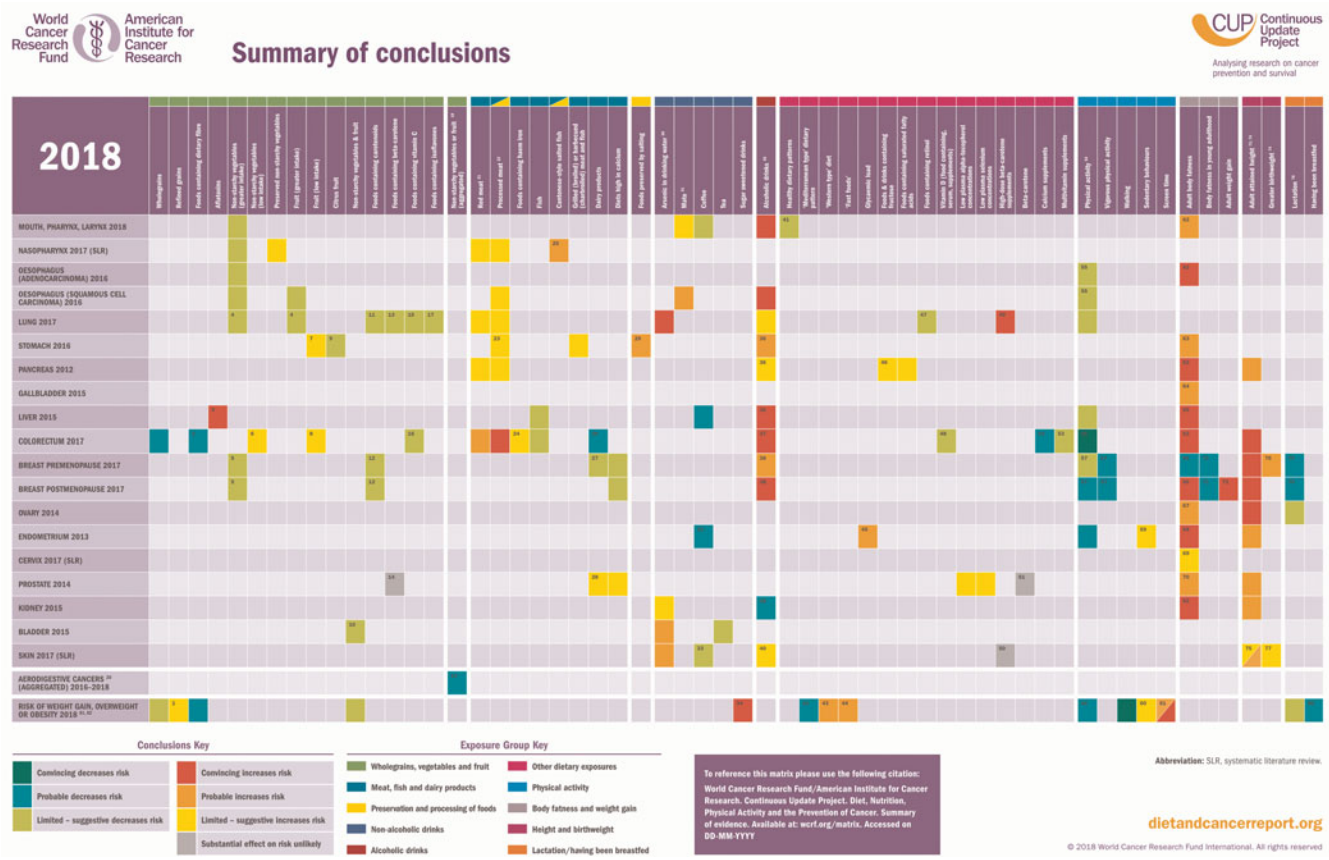

Fig. 2. WCRF summary of conclusions[30]. Figure 2 shows the WCRF 2018 summary matrix, which details associations where the exposure was graded as having a 'strong convincing'/ 'strong probable' or 'limited suggestive' likelihood causality for its impact on cancer risk. This material has been reproduced from the World Cancer Research Fund/ American Institute for Cancer Research. Diet, nutrition, physical activity and cancer: a global perspective. Continuous update project expert report 2018. Available at: https://www.wcrf.org/research-policy/library/matrix-for-all-cancers/.

The 2018 Third Expert Report emphasised the importance of viewing the recommendations as a comprehensive lifestyle approach conducive to cancer prevention. The report suggested that adopting a holistic perspective would yield greater benefits than concentrating on individual foods or isolated risk factors.

Looking at cancers currently linked with firefighting, higher intake of vegetables and fruits and fibre-containing foods have been shown to reduce the risk of bladder cancer[32], prostate cancer[33], colorectal cancer[34], lymphoma[35], oesophageal cancer[36], thyroid cancer[37] and breast cancer[38].

Dairy products have been associated with a reduced risk of colorectal cancer[34] and breast cancer[39,40]. However, it should be noted that suggestive links between higher levels of calcium and increased risk of prostate cancer have also been found[41].

Fish and omega-3 has shown inverse correlation with colorectal cancer[42]. Coffee has shown promising evidence of reduced risk for several cancers, including melanoma[43], whereas tea (in particular green tea) has been linked with protective effects from bladder cancer[44]. By contrast, red and processed meats are linked with higher risk of colorectal cancer[45] and oesophageal cancer[36].

Alcohol intake is positively associated with multiple cancers, including oesophagus, liver, breast, colorectal, mouth, throat and skin[46]. Conversely, some studies suggest that moderate alcohol intake is associated with a reduced risk of kidney cancer[47], non-Hodgkin lymphoma[48] and thyroid cancer[49]. Thus, its role in cancer prevention remains complex and should be approached cautiously.

Linked with dietary intake, adult body fatness is correlated with at least thirteen different cancers[50], including liver, colon, kidney, oesophageal, breast, thyroid and malignant melanoma cancers, and is the highest single risk factor shown in the WCRF summary of evidence.

Physical exercise is identified by the WCRF as a key protective element against cancer risk, with its functions extending beyond modifying body composition. Friedenreich *et al.* (2010) concluded, from an analysis of data from fifteen European countries, that up to 19% of cancer cases could have been prevented through sufficient levels of physical activity[51].

The Mediterranean diet

The basic parameters of the WCRF dietary advice fall closely in line with the Mediterranean Diet (MD)[28] – a concept first coined in the 1960s by Ancel Keys, which remains one of the most well-known and well-researched diets in the world. While several diets exist which follow similar guidelines to the WCRF report, there is consensus that the 'Mediterranean diet reigns supreme' considering all the evidence and pros and cons of each[52].

While there remains no single fixed definition of the MD pattern (with the lack of homogeneity making meta-analyses difficult)[53], it is characterised by high consumption of vegetables, fruits, legumes, whole grains, nuts and extra virgin olive oil, with moderate intake of fish, dairy products and red wine, and low consumption of red meat, processed foods and sweets. Many

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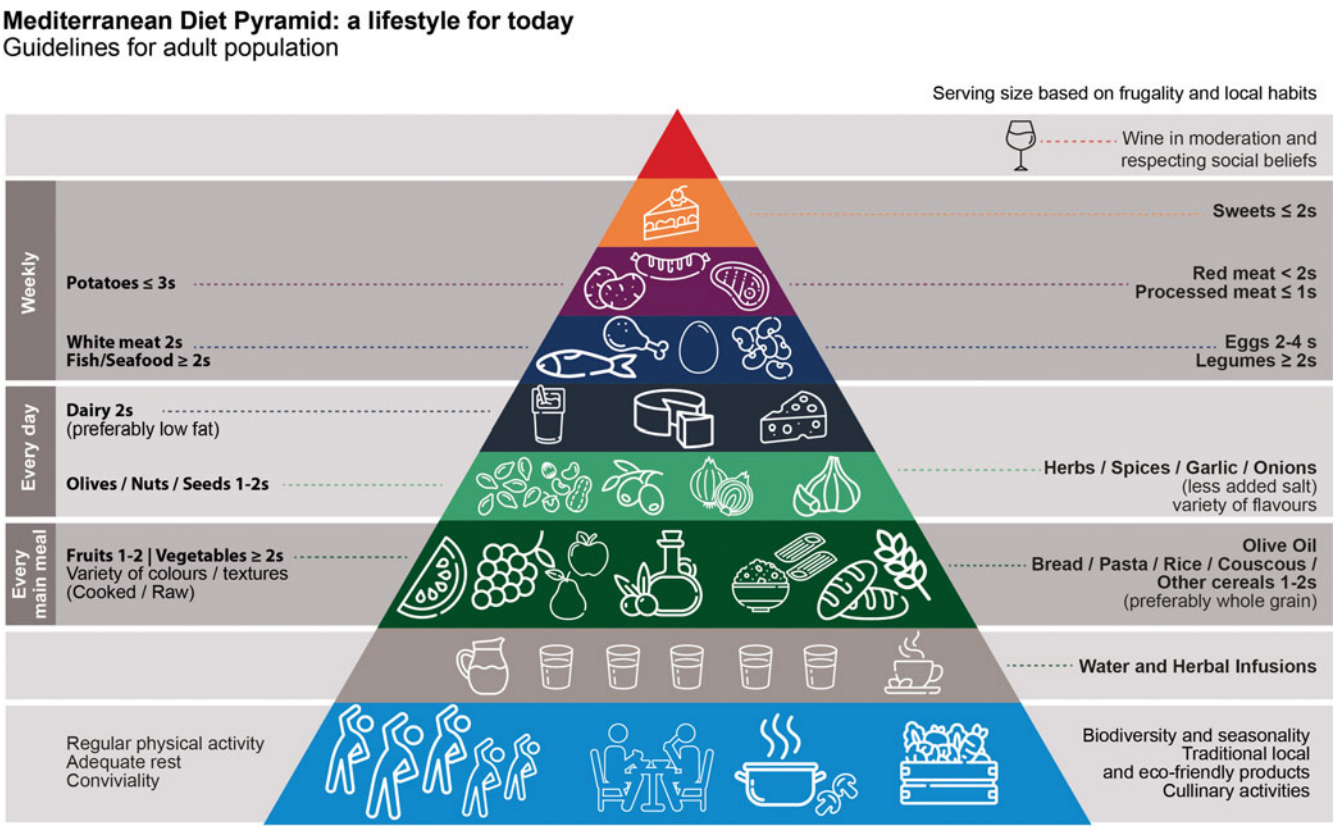

Fig. 3. The Mediterranean diet pyramid. Adapted from Mentella *et al.*[54].

definitions, including that of the United Nations Educational, Scientific and Cultural Organization (UNESCO), also include a holistic view of the Mediterranean lifestyle, incorporating social connections and reinforcing cultural traditions through shared meals, respect for the land and preservation of biodiversity[54] (see Figure 3 for a representation of this).

The Mediterranean diet (MD) is viewed as the most evidence-supported dietary option for those at an increased risk of cancer development or currently diagnosed with cancer[55]. A recent meta-analysis of 117 studies, encompassing over 3 million participants, found that high adherence to the MD was consistently linked with lower cancer mortality[56].

While numerous studies and meta-analyses have demonstrated an inverse relationship between adherence to the MD and cancer risk, some research has reported variability in the strength of associations across different cancer types[57]. These variations are often attributed to differences in study design, definitions of the MD, and genetic or environmental factors, highlighting the inherent complexity of dietary research[57,58]. Nevertheless, the weight of evidence strongly supports the MD as a dietary pattern associated with reduced cancer risk, as highlighted by findings from the European Prospective Investigation into Cancer and Nutrition (EPIC) study. This prospective cohort study, the largest ever conducted on the connection between diet and disease, included over half a million participants. Using a scoring system for adherence to the MD (where nine is the highest possible conformity and zero is the lowest) the study identified that a two-point increase in the MD score correlated with a 12% reduction in overall cancer incidence. This inverse association was considerably stronger than that predicted on the basis of the associations of the individual components of this diet, and points to the value of the holistic nature of dietary patterns[59].

While reasons for its efficacy are complex, it essentially comprises substances that are high in levels of anti-proliferative, anti-inflammatory, anti-angiogenic, anti-metastatic, anti-oxidant and pro-apoptotic factors[58] (Figure 4), which have been shown to be potential leading factors behind cancer development in both *in vivo* and *in vitro* studies[60]. Its rich fruit and vegetable content provides carotenoids, vitamins C and E, folates and flavonoids with antioxidant properties. The diet's high fibre supports gut health by promoting beneficial bacteria that produce anti-inflammatory short-chain fatty acids (SCFA) such as butyrate, reducing systemic inflammation and oxidative stress[58,61].

Key components such as fish, rich in omega-3 fatty acids, combat inflammation, angiogenesis, metastasis and cell proliferation while lowering the reliance on red and processed meats. Whole grains add fibre, protecting the gut by minimising carcinogen interaction and endotoxin absorption, thereby reducing colon cell damage[55]. Although not yet formally assessed in the WCRF's graded evidence, nuts – an integral part of the Mediterranean diet – have been linked in other research to reduced risk of several cancers relevant to firefighters, including breast, colorectal and prostate cancer, through mechanisms including anti-inflammatory and antioxidant effects via their content of healthy fats, polyphenols and micronutrients[62].

Hence, the main elements for which the MD is known have been shown to have positive associations for reducing cancer incidence (with the potential exception of red wine, given its complex relationship with cancer risk[63]), providing a basis for its use to mitigate work place cancer risks. Moreover, the principles of

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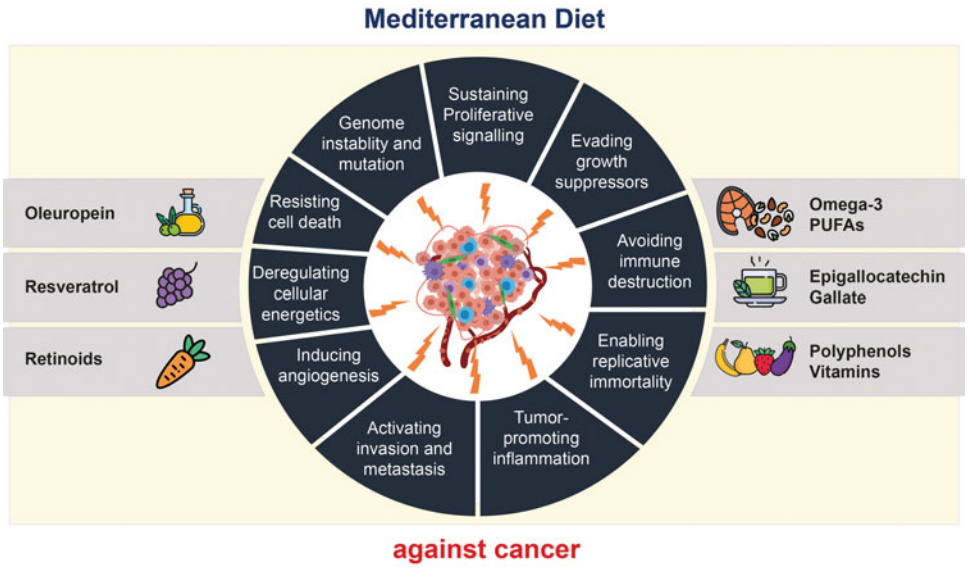

Fig. 4. Mechanisms by which the MD pattern may impact hallmarks of cancer. Foods of the MD that exert anti-tumoural activities by targeting the various hallmarks of cancer include olive oil, red wine, fruits, legumes and vegetables, which contain bioactive molecules such as oleuropein, resveratrol, retinoids, vitamins, epigallocatechin-gallate and omega-3 polyunsaturated fatty acids (PUFA). Adapted from Augimeri and Bonofiglio[58].

the MD can be adapted to fit UK dietary preferences and budgets, using alternatives such as rapeseed oil instead of olive oil or tinned fish for fresh fish. Beyond practicality, the MD framework can also accommodate seasonal and environmental considerations, with local substitutions helping maintain dietary integrity in non-Mediterranean climates. The New Nordic Diet, for instance, was developed on similar principles using regionally available produce and offers a useful model for how dietary traditions can be both nutritionally effective and ecologically adapted[64].

It is worth noting that the original studies that observed the health benefits of the MD focused on its reduction of coronary heart disease risk[65]. Studies since then have linked it with multiple other disease outcomes[66].

Owing to the MD's correlation with reduced obesity and associated poor health outcomes[67], American fire services have recently begun to promote this dietary pattern among firefighters, prompted by the high levels of obesity among US fire service workers[68]. This led to the US Department of Homeland Security awarding a Harvard team of scientists a $1·5-million, 3-year competitive research grant entitled 'Feeding America's Bravest: MedDiet-Based Interventions to Change Firefighters' Eating Habits and Improve Cardiovascular Risk Profiles' which focused on changing the American Firefighters' eating plans to align with the MD[69].

Current dietary habits and cancer risk in firefighters

While several studies have examined the diet of American firefighters, similar research on UK firefighters is lacking. In the absence of such data, it is reasonable to hypothesise that the diet of UK firefighters follows similar patterns to those of the general population, suggesting dietary factors that may influence cancer risk for UK firefighters.

Conformity to the MD style of eating in the UK is extremely low. In 2007, the UK Department of Health developed the Eatwell Plate (now the Eatwell Guide) to provide nutritional guidelines. This guide outlines recommended portions of dietary intake in a structure very similar to the MD. An assessment by Sheelbeek *et al.*[70] found that only 1 in 1000 adhere to the nine key government guidelines. According to the National Diet and Nutrition Survey published in 2018[71], less than one-third of UK adults consume the recommended amount of fruit and vegetables. Sugar intake is more than double the recommended limit across all age groups, oily fish consumption is half the guideline, and while females meet recommendations for red and processed meat, males exceed them. Despite a 30 g daily fibre guideline, the UK average is just 18 g.

Comparisons with other European countries, as demonstrated by data from the EPIC study[72], reveal the extent to which British dietary habits differ from those followed on the continent, as shown in Figure 5.

Recent body mass index (BMI) figures for UK firefighters show a mean value of 26·7[73]. While BMI does not always accurately reflect body composition – especially in muscular individuals – it is nonetheless a useful population-level indicator. Robust UK data on firefighter body composition are limited, highlighting the need for further targeted research. In the meantime, studies among firefighters in the USA have shown that elevated BMI in this group often reflects true excess adiposity rather than increased muscle mass[68]. While global studies of firefighter BMI are limited[74], data from the USA[75], Turkey[76], Iran[77] and Germany[78] all follow a similar trend towards excess body weight, reflecting a working population potentially vulnerable to cancer associated with greater body fatness, as well as work exposure to carcinogens.

Preliminary research into the gut microbiome of firefighters, although currently limited to USA-based studies, suggests significant disruptions likely linked to occupational exposures and dietary patterns. For example, a recent pilot study observed reduced microbial diversity and an increased presence of pathogenic bacteria among firefighters, potentially contributing to immune dysregulation and chronic inflammation[79]. Another study linked occupational hazards, such as toxin exposure, to changes in gut health that might exacerbate vulnerability to disease[80]. Although these findings are preliminary, they underscore the interplay between occupational risk factors and dietary inadequacies, warranting further investigation in UK contexts.

Firefighter specific diets part 1 – the potential for future development

Although the MD has demonstrated promising results in reducing cancer risk among the general population, it is crucial to consider the unique carcinogen exposure that firefighters face. While

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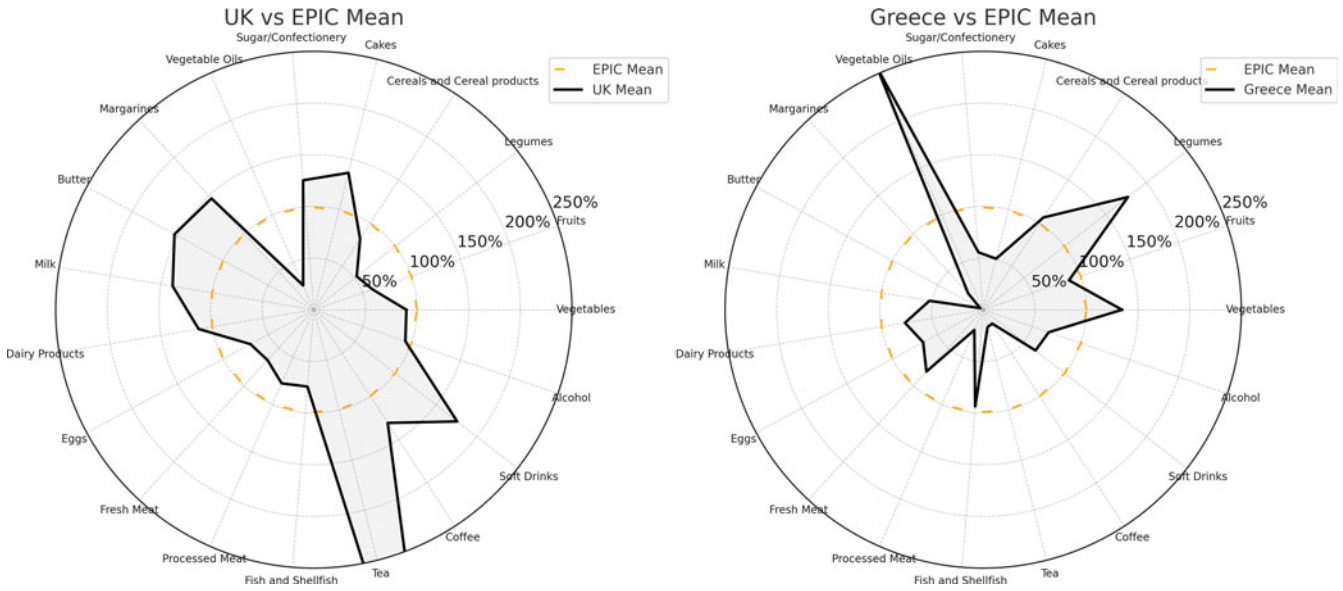

Fig. 5. Comparison of average food consumption in Greece and the UK relative to all-EPIC-country averages. Points inside the dotted circle indicate below-EPIC-average consumption; points outside indicate above-average consumption. Greece demonstrates high intake of vegetable oils, legumes and vegetables, whereas the UK shows high consumption of sugars, cakes, soft drinks and butters/margarines. Adapted from Slimani *et al.*[72].

current human trials are limited, various mechanistic and early-stage studies have explored the chemo-preventive potential of specific foods and nutrients against carcinogens present in fire effluents, offering hope for the development of more tailored nutritional guidelines in the future. The following examples highlight emerging research in this area. These studies were selected to illustrate the breadth of potential nutrient-mediated detoxification or mitigation strategies but are not exhaustive. As many are derived from animal models or *in vitro* research, they should be viewed as hypothesis-generating and interpreted within the broader hierarchy of nutritional evidence. As discussed later in the manuscript, such findings remain exploratory and are not yet directly prescriptive.

For instance, sulforaphane, a compound found in cruciferous vegetables, and in particularly high concentration in broccoli sprouts, has garnered attention for its potential anticancer properties[81]. Trials in mice have shown it to reduce carcinogen induced stress when the lungs were subjected to benzo[a]pyrene (BaP) (one of the most prevalent PAH to which firefighters are exposed)[82].

A human trial conducted in China used a broccoli sprout beverage to examine the potential detoxification of benzene in people subject to high levels of airborne pollution.

Urinary analysis of subjects found it elicited dose-dependent benzene detoxification[83].

Fish oils also show promise in cancer prevention. In mice, they were found to block the formation of hepatic DNA adducts by detoxifying multiple PAHs, including BaP, benz(a)anthracene and chrysene[84]. The chemo-protective potential of fish oil has also been demonstrated in *in vitro* studies using human lung cells treated with BaP[85], while omega-3s found in oily fish have been shown to inhibit free radical increases in rats exposed to high levels of formaldehyde[86]. However, caution is warranted due to the bioaccumulation of heavy metals in fish, which may compound the heavy-metal burden in firefighters. To balance benefits and risks, intake of fish products should not exceed recommended levels. Smaller or shorter-lived fish species such as salmon, sardines and mackerel offer safer options owing to their lower potential for heavy metal bioaccumulation[87].

Beyond nutrients like omega-3s and sulforaphane, plant-based compounds and micronutrients such as garlic, selenium and folate have demonstrated protective effects against specific fire contaminants through detoxification and cancer-preventive mechanisms. Tea (in particular, green tea and its constituents) has been found in animal studies to reduce the potential toxic risks of Asbestos[88], BaP[88–90], PCB 126[91] and nickel[92]. Similarly, retinoids – derivatives of vitamin A, found naturally in various plant and animal sources – have been linked with inhibiting the cytotoxic effects of BaP in both *in vitro* and *in vivo* studies[93–95]. Garlic, a food rich in bioactive compounds, has demonstrated protective effects against chromium-induced carcinogenicity in laboratory studies, attributed to its antioxidant properties and ability to activate detoxification pathways[96,97]. Selenium and folate have also demonstrated protective roles against arsenic exposure. Selenium intake has been associated with reduced incidence of arsenic-related premalignant skin lesions in populations exposed to arsenic-contaminated drinking-water[98], while folate supplementation was shown to enhance arsenic methylation and urinary excretion in a randomised controlled trial, potentially lowering health risks associated with arsenic exposure[99]. Although these studies focus on arsenic exposure from drinking-water, their findings suggest protective mechanisms that may benefit firefighters. Soy-derived genistein has shown the ability to mitigate DNA damage in breast cells exposed to 7,12-dimethylbenzo[a]anthracene (DMBA) in an *in vitro* analysis[100]. Zinc, found in several animal and vegetable foods, has similarly been linked to protective effects against benzene[101], as well as cadmium accumulation in rats[102].

Fruit and vegetables, and phytochemicals found within them, have been associated in laboratory studies with protective effects against carcinogen-induced damage. For instance, spinach, peaches and quercetin have been shown to reduce genotoxicity caused by BaP exposure in mouse bone marrow models,

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highlighting their potential to mitigate DNA damage[103]. In an *in vivo* study, a green vegetable cocktail effectively reduced the toxic impact of benzene in rats[104], while human case–control studies have similarly noted that higher fruit and vegetable intake is associated with lower oxidative stress markers in individuals exposed to high benzene levels[105].

Body composition and dietary habits have also been studied for their impact on contaminant effects. A 'Western diet', high in saturated fats, was linked to accelerated BaP-induced colon cancer development in rat models[106]. Excess body fat, often associated with such dietary patterns, has been shown to slow benzene removal from the body, increasing susceptibility to its effects[107]. In addition, two separate *in vivo* studies highlighted that diets high in fat and low in minerals significantly increased lead absorption in *in vitro* and animal models[108] and in rats[109].

The amino acids glycine and cysteine (in the form of *N*-acetylcysteine) have been shown to improve glutathione deficiency and mitigate oxidative stress in studies involving aged mice and a limited sample of older adults[110]. Glutathione plays a central role in detoxification and cellular defence, and its decline with age may contribute to increased cancer susceptibility[20,21]. This may be particularly relevant to older firefighters with long-term contaminant exposure. These findings suggest potential dietary strategies for supporting antioxidant capacity in this at-risk group. Alpha-lipoic acid has also been found to attenuate the age-related decreases in glutathione synthesis in *in vitro* studies, and *in vivo* studies on rats[111].

Also of note in the potential reduction of cancer risk is the option of manipulating diet through controlled energy intake[112]. In mice treated with 3-methylcholanthrene (a PAH and known firefighter risk factor), tumour development and tumour incidence were greatly reduced under caloric restriction[113]. Fasting-mimicking diets, tested on mice, were shown to reduce risk factors/biomarkers for cancer, as well as diabetes and cardiovascular disease, without significant adverse effect[114].

A recent study has supported the feasibility of time restricted eating (TRE) for firefighters in America. The Healthy Heroes randomised controlled trial (RCT) separated a body of firefighters into two groups. The control group and the study group were both set a fixed dietary intake matching the MD format. The TRE group restricted eating to a 10-hour window and reported improved quality of life and showed improved cardiometabolic health markers with no adverse effects[115].

These studies provide a sample of the extensive research that illustrates how nutrition can potentially reduce the cancer risk associated with exposure to fire effluents and are summarised in Table 1.

Firefighter-specific diets part 2: challenges in future development

While the studies discussed in part 1 highlight the potential of specific nutrients and dietary patterns in mitigating the cancer risks associated with exposure to fire effluents, no definitive conclusions can be drawn about the practical feasibility or safety of the proposed protective mechanisms. None of these mechanisms has undergone the rigorous evaluation needed for recognition by the WCRF's Global Cancer Update Project[29]. While chemical interactions are demonstrated in laboratory settings, and human studies suggest correlations between certain nutrients and cancer outcomes, a comprehensive range of analytical methods is necessary before causality can be confidently established.

In vivo and *in vitro* studies contribute valuable insights for future exploration, demonstrating biological plausibility for human study. However, these studies alone cannot provide proof of efficacy in human subjects. *In vitro* studies fail to assess nutrient bioaccessibility or replicate the complex interactions of real diets, while animal studies, despite controlled conditions, use carcinogen and nutrient levels unrepresentative of human exposure. This makes it hard to assess how reflective, or safe, any results would be in real life.

RCT in humans are the gold standard for identifying factors involved in the development and prevention of disease, but they are challenging in nutrition and cancer research due to confounding factors, the length of time required between intervention and cancer outcomes, non-adherence and the complexity of dietary interactions[31,116].

These trials often use supplements rather than whole dietary changes, but the efficacy of supplements is uncertain because they lack the synergistic mix of nutrients found in whole foods[117]. For example, a Portuguese RCT on antioxidants in firefighters showed no significant improvements in immune response, concluding that supplements were less effective than natural dietary components in supporting immunocompetence and reducing inflammation[118].

Beyond the potential inefficacy of supplement-based interventions, safety concerns also exist. The WCRF advises against using supplements to prevent cancer[27]. This reflects the 1996 CARET study, which investigated the use of high-dose β-carotene and vitamin A supplements to prevent lung cancer in smokers. The trial was halted when early analysis revealed not only a lack of benefit but also an increased risk of harm, with 28% more lung cancers and 17% more deaths in the active intervention group. The implications of this trial for future studies and study design have been widely accepted: safety and efficacy should be demonstrated before recommending vitamin supplements to any population[119].

In 2014, Fardet and Rock criticised the analyses of single nutrients or food groups as a reductionist approach not adequate in studies on the preventive effects of nutrition in chronic diseases such as cancer[120]. By contrast, dietary patterns may take into account synergistic and antagonistic interactions between the components of a food matrix, thus yielding a holistic net effect of diet[121]. For this reason, the MD should remain the key aim for firefighter nutritional protection, due to the synergistic effect of its components[58].

Therefore, the MD remains a practical strategy for firefighters to reduce cancer risk. Yet, cultural and occupational barriers, including food habits and job demands, must be addressed to enable sustainable dietary improvements that extend beyond theoretical recommendations.

Challenges and solutions for changing firefighter diets

Understanding the obstacles that hinder the implementation of tailored dietary strategies is crucial. Research into UK firefighters' understanding of cancer risk is lacking; however, UK population data suggest a widespread lack of awareness on this subject. In 2023, a Cancer Research UK survey found that only 21% of the UK population understood the link between cancer and diet, and fewer still recognised the risks posed by physical inactivity (17%) and obesity (10%)[122].

The lack of knowledge on cancer risk is not limited to the UK. Surveys of American firefighters, published in 2024, showed that most, including those affected by cancer, had received no education on diet's role in cancer prevention[123].

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Table 1. Examples of nutrients and dietary factors with potential effects on fire contaminants

Food/nutrient	Targeted contaminant	Mechanism of action and observed outcomes	Study context
Sulforaphane/ broccoli sprouts	- BaP*	- Modulates detoxification enzymes to reduce carcinogen-induced stress	- Mouse (lung carcinogenesis)[82]
	- Benzene	- Enhances benzene detoxification through glutathione pathways	- Human RCT† (pollution exposure)[83]
Omega-3/fish oils	- BaP* and other PAH§	- Reduces DNA adduct formation and enhances detoxifying enzyme activity	- Mouse (hepato-carcinogenesis)[84]
	- BaP*	- Alters enzyme activity to mitigate DNA adduct formation	- Human cell line (adeno-carcinoma)[85]
	- Formaldehyde	- Restores antioxidant enzyme activity and reduces oxidative stress markers	- Rat (brain oxidative stress)[86]
Green tea	- Asbestos + BaP*	- Reduces lung carcinoma incidence and prolongs survival	- Rat (lung carcinoma)[88]
	- BaP*	- Reduces oxidative stress and improves carcinogen excretion pathways	- Rat and mouse (various models)[89,90]
	- Nickel	- Reduces oxidative stress and DNA damage (n.b. white tea outperformed green tea)	- *In vitro* (human plasma)[92]
	- PCB 126‖	- Reduces oxidative stress by activating key antioxidant pathways	- Mouse (PCB-induced stress)[91]
Retinoids	- BaP*	- Inhibits procarcinogen activation and enhances detoxifying enzyme activity	- Rat and human cell studies[93–95]
Selenium and folate	- Arsenic	- Reduces arsenic toxicity through enhanced detoxification and antioxidant pathways	- Human case–cohort and RCT†[98,99]
Genistein/soy	- DMBA‡	- Reduces oxidative stress and DNA damage by suppressing key metabolic enzymes	- Cell (non-tumorigenic breast cells)[100]
Zinc	- Benzene	- Boosts antioxidant enzymes and reduces liver damage	- Rat (benzene-induced liver toxicity)[101]
	- Cadmium	- Zinc deficiency increases cadmium accumulation and disrupts detoxification	- Rat (dietary exposure)[102]
Fruit and vegetables	- Benzene	- Restores blood parameters, protects spleen, boosts immune response and reduces oxidative stress markers	- Rat (benzene-induced disorders)[104] Human case–control[105]
	- BaP*	- Reduced BaP-induced genotoxicity; flavonoids inhibited DNA damage in a dose-dependent manner (study used spinach, peaches and quercetin)	- Mouse (bone marrow micronucleus assay)[103]
Garlic	- Chromium	- Activates antioxidants and detoxification pathways	- Rat (liver toxicity)[97]
Western diet (high fat, low fibre)	- BaP*	- Increases colon tumour incidence via elevated cholesterol, triacylglycerol and leptin	- Rat (PIRC model, colon carcinogenesis)[106]
High body fat content	- Benzene	- Slows benzene elimination, prolonging exposure and increasing susceptibility	- Rats (chronic exposure), humans (experimental exposure)[107]
High-fat, low-mineral diet	- Lead	- Increases lead absorption; reduced with higher mineral intake	- Rat (dietary exposure studies)[108,109]
Caloric restriction	- 3-Methylcholanthrene	- Reduced tumour incidence by enhancing T cell immune responses	- Mouse (tumorigenesis, and immune response)[113]

Note: This table provides selected examples of studies exploring nutrient-mediated detoxification or mitigation of fire contaminant toxicity. It is not exhaustive but aims to demonstrate the breadth of current research. The 'Food/nutrient' column includes a mix of whole foods, bioactive compounds and micronutrients, reflecting the diverse forms in which protective effects have been studied.
*BaP, Benzo[a]pyrene.
†RCT, randomised controlled trial.
‡DMBA, 7,12-dimethyl-benz[a]anthracene.
§PAH, polycyclic aromatic hydrocarbons.
‖PCB, polychlorinated biphenyl.

However, even among populations who are given direct dietary advice for health conditions, information alone rarely drives significant change[124].

This is partly influenced by the UK's food culture and environment, which is commonly described as obesogenic[125]. Drawing on WHO data and broader public health sources, Omoleke – author of the cited review – explains how the widespread availability of ultra-processed foods contributes to this environment and can shape dietary habits. Vending machines, online food delivery services and convenience outlets serve as prime examples of such easy-access sources of energy-dense, nutrient-poor foods. As discussed by Roberto *et al.* in a Lancet

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series on obesity[126], although individuals have some control over their diet, the modern food environment has introduced an influx of hyper-palatable foods high in sugar, fat and salt that appear to surpass the rewarding properties of non-processed foods. Emerging evidence suggests these foods have effects on the reward pathways in the brain, making it harder for people to regulate their food intake and maintain a healthy diet[127].

Such foods are often cheaper than their healthier counterparts, with the UK Fenland study noting that the higher cost of adherence to the MD was seen as a barrier by many. However, the study noted that this cost difference could potentially be mitigated not only by the natural reduction in unhealthy items such as red and processed meats, inherent to the MD, but also by prioritising lower-cost healthy components, such as pulses, legumes and canned fish, over more expensive items within the diet[128]. While such substitutions might lower costs, they require substantial changes in purchasing habits and taste preferences and, in some cases, time and cooking skills – which may well be particularly challenging for individuals accustomed to the rewarding and convenient nature of highly processed foods.

Firefighters face unique challenges that heighten the difficulties discussed, such as work-related stress, trauma exposure and disrupted sleep[24,129]. These job-related factors intensify barriers to maintaining healthy dietary and lifestyle habits, contributing to a cycle of poor nutrition, mental health issues and overall well-being.

A recent UK paper explored sleep, mental health and contaminant exposure, finding high levels of sleep problems among UK firefighters (61%). Those who reported sleep problems were over 4 times more likely to report any mental health disorder, 2·9 times more likely to report anxiety and 2·3 times more likely to report depression than those who did not report sleep issues. The study found a direct correlation between such disorders and likelihood of contaminant exposure. While causality cannot be confirmed, the authors suggest that contaminant exposure may contribute to mental health difficulties through direct biological effects – such as neurotoxicity or endocrine disruption – or indirectly via concern over health risks and contaminant-linked illness. These pathways may also disrupt sleep, further undermining psychological well-being[130].

Evidence shows that poor mental health, poor sleep and poor dietary choices are interconnected, with declines in one often exacerbating issues in the other two[131,132].

An American observational study of firefighters, examining job-related stresses and health habits, found a direct link between the two. Headrick[133] reported that emotional demands during the shift positively correlated with unhealthy eating and alcohol use during the time off duty. Such off-duty habits led to fatigue before the next shift, which exacerbated the perception of emotional demands during the shift, leading to further unhealthy behaviour[133].

A Swedish study into shift workers noted a high incidence of metabolic disorders and diseases, linked to the quality of the diet and irregular timing of eating. However, other factors that affect metabolism are likely to play a part with the association to metabolic disorders, including psychosocial stress, disrupted circadian rhythms, sleep debt, physical inactivity and insufficient time for rest and revitalisation[134].

Biochemical factors at least partly underpin the association. Sleep curtailment is associated with decreased leptin levels and elevated ghrelin levels, leading to increased hunger and appetite[135].

Inadequate sleep may especially increase consumption of unhealthy foods, as demonstrated by an Australian study on firefighter eating habits which found that night shifts are associated with a higher intake of foods rich in sugar, fat and energy. Fatigue was identified as a key contributor to this pattern[136]

A study examining Spanish firefighters showed similar results, identifying night shift work and the associated sleep difficulties as the cause of a higher intake of saturated fats and a higher injury incidence[137].

These studies demonstrate that there are multiple factors within firefighters' work culture which can lead to an accumulation of unhealthy behaviours and make poor dietary choices more likely. However, supportive environments can mitigate the effects of work stress on diet. The aforementioned study by Headrick[133] shows that partner support for healthy eating at home and a perception of healthy eating among colleagues help to moderate unhealthy behaviours, demonstrating the importance of a positive food culture at work. Such change relies heavily on group norms. Without peer participation, individual intentions are less likely to translate to long-term dietary changes in firefighters[133].

The value of group norms in shaping dietary behaviour is further illustrated by findings from the PHLAME (Promoting Healthy Lifestyles: Alternative Models' Effects) intervention. This team-centred programme demonstrated that improving dietary norms among coworkers, alongside increasing knowledge of the benefits of fruits and vegetables, significantly enhanced intake among firefighters[138].

Herein lies one of the key factors to firefighter diet: the work dietary culture.

In the UK, firefighters typically eat communally through a messing system (often referred to simply as 'the mess') – a long-standing tradition where each crew co-operatively funds, prepares and eats shared meals. This shared eating format aligns with the social aspect of the MD. Field research in the USA has shown that this approach, free from management influence, fosters a co-operative work environment essential for group performance[139]. Both qualitative and quantitative analyses from the study highlighted a direct correlation between the level of fire station commensality and work-group performance.

However, the mess culture presents both challenges and opportunities for improving firefighter diets.

In an examination of American firefighter diets, Sotos-Prieto identified fire service food culture and a lack of nutritional education within stations as being key barriers to change[140]. Even when firefighters recognise the importance of a healthy eating pattern, they reported that their own food choices were often influenced by colleagues[141].

The main barriers to change include a number of cultural, social, economic and logistical factors.

In most fire crews, one team member voluntarily manages shared meal planning and grocery shopping. Choices are normally shaped by practical needs: meals must be affordable, hearty and able to handle disruptions from fire calls without losing their appeal. For this reason, where food education is lacking, less healthy, preservative rich options high in protein, saturated fats and refined carbohydrates are staple choices of the UK mess rota.

Attempts to modernise messing have found that small-scale interventions have little success[142,143], concluding that 'intensive and culturally tailored prevention interventions targeting nutritional behaviours are needed at the individual, group, and organisational levels'[142].

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By adopting these approaches, successful interventions have been done in the USA and in the UK, harnessing the mess culture as a tool to drive positive mindset around healthy eating.

Hershey *et al.* found that the Harvard-led intervention to encourage the MD among fire crews brought about significant improvements in participants' MD adherence[144]. This came from an on-station intervention which used multiple angles to promote healthy eating. Education was provided via an online platform, which contained brochures on MD recommendations, a firefighter-specific Mediterranean Diet Pyramid, grocery shopping tips, sample recipes, video interviews with exemplary firefighters practicing the MD, and access to additional resources, such as chef-led cooking demonstrations in fire station kitchens, access to supermarket discounts, free samples of MD foods, email announcements and reminders, and family and peer education and support.

Analyses in the UK and in the USA have shown that, when the MD is presented to firefighters, it is viewed more positively than other potential dietary schemes[145,146].

Two separate London-based interventions in fire stations, which aimed to promote the MD to stations, found that, when teaching was given regarding how to make low-cost, low-burden meals in line with MD principles, participant feedback was overwhelmingly positive even from low-intensity formats of input[145,147].

As a final tie-in with diet and lifestyle, it should be highlighted that physical activity is also a key component of the MD pyramid[54]. Beyond its direct effects on body composition and internal functioning, UK research on firefighters shows that physical activity reinforces the feedback loop between positive lifestyle habits and healthy eating[148]. Furthermore, studies highlight its critical role in reducing cancer risk among firefighters, particularly through improving cardiorespiratory fitness and reducing inflammation, underscoring the importance of its integration into occupational health strategies[22].

Discussion

Cancer is a significant occupational health risk for UK firefighters due to chronic exposure to carcinogens such as benzene, asbestos and PAH in fire effluents. While protective measures have reduced risks, exposure persists, compounded by factors including disrupted sleep and stress, which impair the body's detoxification and repair mechanisms. This underscores the need for supplementary strategies, such as dietary interventions, to mitigate risks.

The Mediterranean diet offers a promising approach, supported by evidence linking it to reduced cancer incidence and mortality through its anti-inflammatory and antioxidant properties. Despite these benefits, UK firefighters face barriers to adopting healthier diets. Elevated BMI within this group, coupled with broader UK population data and the known dietary trends of shift workers under stress, suggests low adherence to healthy dietary patterns within this workforce. However, the communal culture of the fire service provides an opportunity for promoting healthier eating and lifestyle through targeted education and peer support. Successful interventions in the USA and UK show that integrating MD principles into communal dining can encourage long-term dietary improvements, but only when supported by targeted education, peer involvement and culturally tailored strategies, as outlined in this review. These methodologies are essential to ensure that such interventions are practical, sustainable and effective, while preserving teamwork and camaraderie.

This review serves as a dual call to action. First, it highlights the need for more firefighter-specific nutritional research, particularly randomised controlled trials, to identify and validate effective strategies for reducing cancer risk. An example of the type of targeted research required is the ongoing trial in Tucson, USA, which investigates sulforaphane's detoxification potential in firefighters undergoing live fire training[149]. Results, expected in late 2027, could offer valuable insights into practical interventions tailored to this population. This trial exemplifies the critical shift toward targeted research – a direction this review strongly advocates.

Second, beyond research, this review calls for fire service officials to prioritise investments in dietary education, training and support. These efforts must be collaborative, leveraging the communal bonds fostered through crew commensality to promote sustainable change. Ethical considerations, such as the affordability of healthy foods and the responsibility placed on firefighters to adopt dietary changes in the absence of systemic support, must be addressed to ensure equitable and sustainable interventions.

In addition, organisational and environmental factors should be considered when designing interventions, such as kitchen resources for preparing healthy meals, the nutritional quality of staple ingredients kept on station and the constraints of fixed shift schedules. For example, initiatives to provide basic whole foods or form partnerships with local suppliers could help fire stations prepare healthy meals more easily and affordably.

The findings of this review extend beyond firefighting, offering valuable insights for other high-risk professions such as mining, construction and industrial work, where occupational carcinogen exposure and barriers to healthy eating are also prevalent. Future research could refine these insights to address specific challenges faced by these groups.

While this review highlights promising dietary strategies, it also underscores the complexities of developing a universal diet that addresses the diverse needs of this population. Factors such as genetic variability, differing exposure levels to fire contaminants, and the unpredictable nature of firefighting operations – where the frequency and intensity of fire encounters can vary greatly between stations and individuals – mean that no single dietary approach will suit everyone perfectly. Nevertheless, foundational dietary patterns like the MD provide a scientifically supported starting point for population-wide recommendations. Looking ahead, advancements in research and technology – such as genetic testing, real-time biomarker tracking and personalised health analytics – may enable further refinement of dietary strategies. Bridging the current research gaps will be critical to achieving this goal, while existing knowledge can already guide meaningful dietary improvements.

Conclusion

Addressing the cancer risks faced by UK firefighters demands a holistic approach that integrates protective measures with sustainable lifestyle changes. Efforts must prioritise whole foods, community involvement and physical activity to create a positive cycle of health that aligns with the unique occupational realities of firefighters. Such an approach positions the Mediterranean diet not merely as an ideal but as a practical, sustainable strategy to reduce cancer risks and safeguard the long-term health of those who risk their lives for public safety.

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