Australian-German Association Fellowship 2015

Collaborative Australian-German investigations in neuroscience to solve complex brain diseases

Fellowship Report

Ashwyn Perera

Declaration of Authorship

The research presented in this report was conducted and interpreted solely by the author, except where explicitly stated in the text. This report is being submitted as part of the Australian-German Association (AGA) / Goethe-Institut Fellowship 2015 and has not been submitted elsewhere.

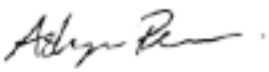
The report contains no material previously published or written by another author except where due reference is made in the text.

Laboratory notebooks and experimental data remain with the Innate Immunity Group, Institute of Neuropathology, Universitätsklinikum Freiburg, Germany.

Scope and target audience

This report is intended for a lay audience with no prior knowledge in biomedical science, and has been written accordingly. Due to intellectual property considerations of experimental results that have yet to be published, data have been described in a purely qualitative fashion.

More detailed information regarding laboratory methods and results are available upon request.



Ashwyn Perera
Melbourne, 25. August 2016

About the Author

Since specialising in neuroscience during my Bachelor of Science (Honours) at the University of Melbourne, Australia, I have contributed to a range of neuroscience research teams both as a student and as a professional. Projects included addressing childhood deafness, autism spectrum disorder and, most recently and most relevant to this report, multiple sclerosis.

Throughout my progression through secondary and tertiary education, I have immersed myself in German language and culture. This includes completing German as a subject throughout high school, being awarded a 3-month school exchange scholarship from Scholarships for Australian-German Student Exchange (SAGSE) and subsequent involvement in the alumni organisation, the German Australian Students' Society (GASS). During my undergraduate studies I completed an exchange at the University of Freiburg, and was invited back to the university after my graduation to complete an internship within the Department of Otorhinolaryngology. I took part in the winter language program offered by the German Academic Exchange Service (DAAD) and completed a Diploma of Languages in German concurrent to my undergraduate studies before receiving the Australian-German Association (AGA) Fellowship in 2015.

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Abbreviations

AGA	Australian-German Association
DFG	German Research Foundation *(Deutsche Forschungsgemeinschaft)*
FINMH	Florey Institute of Neuroscience and Mental Health, Melbourne, Australia
GDP	Gross domestic product
GF	Germ-free (mice lacking gut bacteria)
MAMPs	Microbial-associated molecular patterns
MS	Multiple sclerosis
SCFAs	Short-chain fatty acids

Abstract

As an AGA Fellow, I conducted a 10-week research project in the laboratory of the Innate Immunity Group, Institute of Neuropathology, Universitätsklinikum Freiburg, Germany, headed by Prof. Dr. Marco Prinz. Coming from a background in multiple sclerosis research at the Florey Institute of Neuroscience and Mental Health in Melbourne, Australia, I was able to learn from the expertise of Prof. Prinz's group regarding their research focus, microglia– the defence cells of the brain. Given the relevance of microglia in multiple sclerosis disease progression, I aimed to apply their knowledge in microglia form and function to the current themes in multiple sclerosis research. Previous studies have shown that microglia in the brain are affected by bacteria that reside in the gut. We sought to better understand how gut bacteria can influence microglia in the well-protected brain. We found that gut bacteria not only affect microglia in the brain, but also the defence cells in the liver. We reasoned that the liver may play a role in the communication between the gut and the brain. Better understanding the mechanisms of this 'gut-brain axis' may prove relevant when seeking to modulate microglia function for the benefit of multiple sclerosis patients. My research stay as part of the AGA Fellowship allowed me to develop scientific collaborations between Australian and German research groups, an apt medium through which bilateral relations between the respective countries can be strengthened.

Introduction

Biomedical research in Australia and Germany

Australia and Germany are amongst the leaders in innovative biomedical research. The aims of such research are two-fold. Fundamentally, biomedical research seeks to better understand the human condition from a biological perspective; how body systems function and how this impacts our way of life. Armed with this knowledge, we can better understand situations in which the human condition is compromised; namely during sickness or disease. The ultimate goal is to combat these diseases to improve the human condition and our quality of life.

Biomedical research in Germany has a long and rich history. After Latin loosened its grasp up to the mid-17th century, German came to be the lingua franca of scientific journals from the late 19th century up to the early 20th century. Whilst English is now the predominant language of science, many linguistic features still remain. For example, *köhlern*, a verb referring to the adjustment of light settings on a microscope (*Köhlersche Beleuchtung*), named after the German physicist Prof. August Köhler. Germany maintains a pioneering status in biomedical research, with a wide range of university and non-university institutions that ensure a dominant presence on an international scale. A testament to the calibre of the German biomedical research environment is the countless number of Nobel Prize laureates awarded to Germans; behind the USA and the UK, the most of any other country.

In the present day, the German government ensures its persistence as a leading country in research output, in part through the German Research Foundation (*deutsche* Forschungsgemeinschaft; DFG). 2.88% of Germany's GDP is spent on research and development (UNESCO Institute for Statistics, 2016).

The Australian biomedical research landscape is of similar excellence, albeit on a smaller scale. The city of Melbourne has grown into a hub of medical science, providing a conglomerate of universities and institutes producing outstanding research. Of particular note is Prof. Elisabeth Blackburn, alumni of the University of Melbourne and Nobel laureate with her work on telomeres, a protective structure at the end of chromosomes. Australia spends 0.56% of its GDP on research and development (Australian Bureau of Statistics, 2011).

The challenges of biomedical research

There are, however, certain challenges within the biomedical research sector that limit productivity in the field. Unfortunately, it takes more than just an idea and natural curiosity for a research project to come into fruition. The project must compete with others to receive funding from public or private means. Australia and Germany do not share the philanthropic culture seen in the USA, where private individuals often fund projects or even support entire institutes, relieving somewhat the urgency to acquire external funding. Rather, we rely more heavily on public funding (such as the National Health and Medical Research Council in Australia and the *Deutsche Forschungsgemeinschaft* in Germany) and large industry firms in the private sector to support our research. Indeed, this pool of funding is limited, and priority is given to research groups with an excellent track record. Track records are established by the publication of research in scientific journals, each of which having an 'impact factor', allowing the impact and relevance of the research to be quantified. Future funding applications for research often take individuals' publication record into account and as such, the concept of 'publish or perish' is a very real concern. It is paramount that we rise above such politics in the research sector, and ensure that we continue to conduct research with sound intentions; that is, to better understand the human condition, to find treatments for diseases and to ultimately improve our quality of life.

Another challenge, and one that my AGA fellowship project seeks to address, is the need for collaboration. The volume of research undertaken globally is large, and it is critical for this information to be effectively communicated and shared. Taking part in conferences and reading widely in the scientific literature ensures that we keep up with new insights. Each laboratory is highly specialised in their specific field, and therefore has the opportunity to share and benefit from other lines of research. It takes initiative to recognise the benefits of combining the expertise of two laboratories to forge new research directions. It may lead to outcomes that were not initially anticipated; for example, many drugs now used for certain ailments were originally developed for another purpose.

Addressing this issue is one of the aims of my AGA Fellowship research stay; to bring with me the expertise of our laboratory in Melbourne and apply our knowledge to a different context, in the hope of amalgamating our research themes and forging new and novel findings.

Building collaborations between Freiburg and Melbourne

I am a member of the Multiple Sclerosis (MS) Division at the Florey Institute of Neuroscience and Mental Health, Melbourne, Australia. Our research seeks to better understand how MS develops in the human body, in order to then develop targeted treatments for the disease. I visited the Innate Immunity Group within the Institute of Neuropathology at the Universitätsklinikum Freiburg, Germany, headed by Prof. Dr. Marco Prinz. Prof. Prinz's research focuses on a particular defence cell in the brain, termed microglia. Prof. Prinz is regarded internationally as an expert in microglia, and has held conferences and written reviews specific to this special brain cell. In visiting his laboratory, I had the opportunity to combine my focus, MS, with his expertise in microglia.

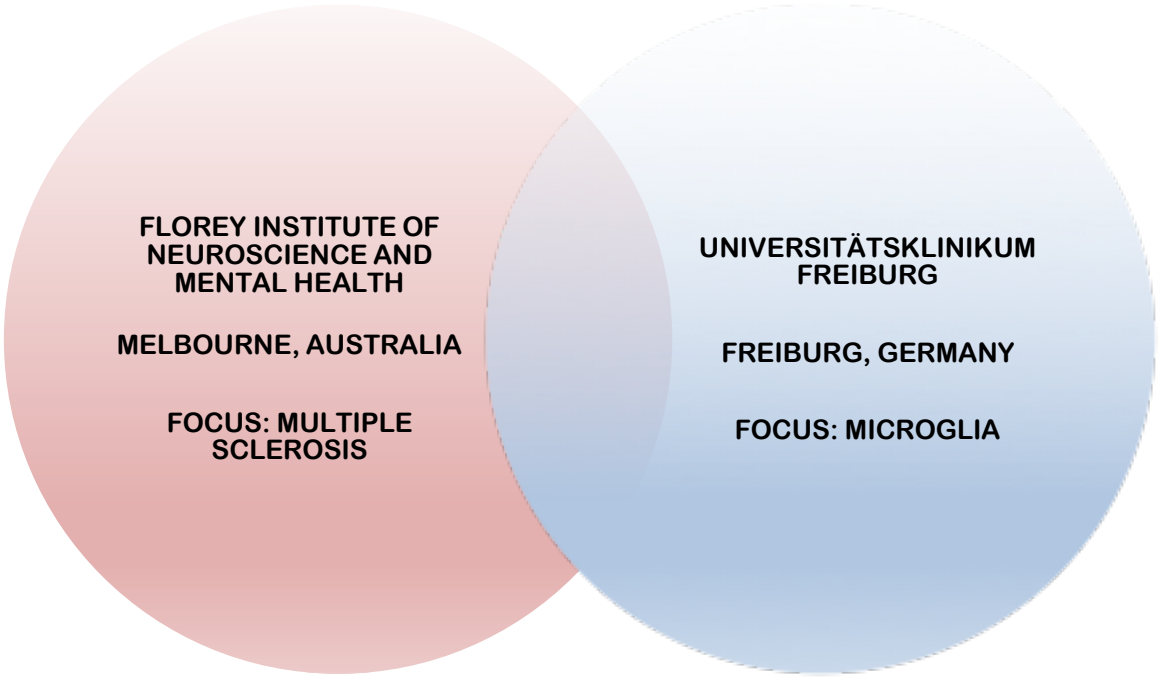

Fig. 1. The AGA Fellowship presents the opportunity to combine the expertise of our respective laboratories to forge new research directions. AO.

Multiple Sclerosis

MS is a disease of the central nervous system, which comprises of the brain and the spinal cord. Within this system is a vast network of neurons, which enables signals to be sent throughout the brain and the rest of the body. Current estimates place the number of neurons in the system at 100 billion, each having approximately 7000 connections with other neurons

(Herculano-Houzel, 2012). Such a vast network allows for the extensive cognitive capacity of the human condition.

Many of these neurons are encased in a fatty layer, the myelin sheath. Layers of myelin sheath wrap around the neuron, enabling the neuron to transmit information at high speed and at low energy cost. Myelin is an integral component of neuron structure, critical to the proper functioning of the central nervous system. The progression of MS begins when this myelin begins to degenerate, a process termed demyelination (Fig. 2).

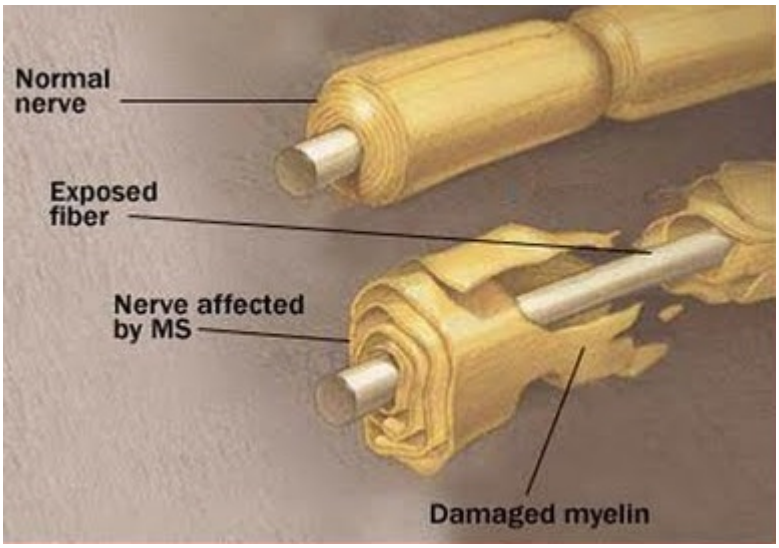

Fig. 2. Neurons of multiple sclerosis patients are demyelinated – the protective myelin sheath has degenerated. Source: www.viralglobalnews.com

One direction of the MS research field is to seek ways to prevent this demyelination or, alternatively, to promote the production of new myelin (remyelination) around the affected neurons. The disease is autoimmune in that the body's own immune cells attack the myelin sheath. Depending on which neurons in the body are targeted, symptoms of MS are wide-ranging and include cognitive and emotional changes, difficulty walking, vision impairment and fatigue (Fig. 3). More than 2.3 million people are affected by MS worldwide.

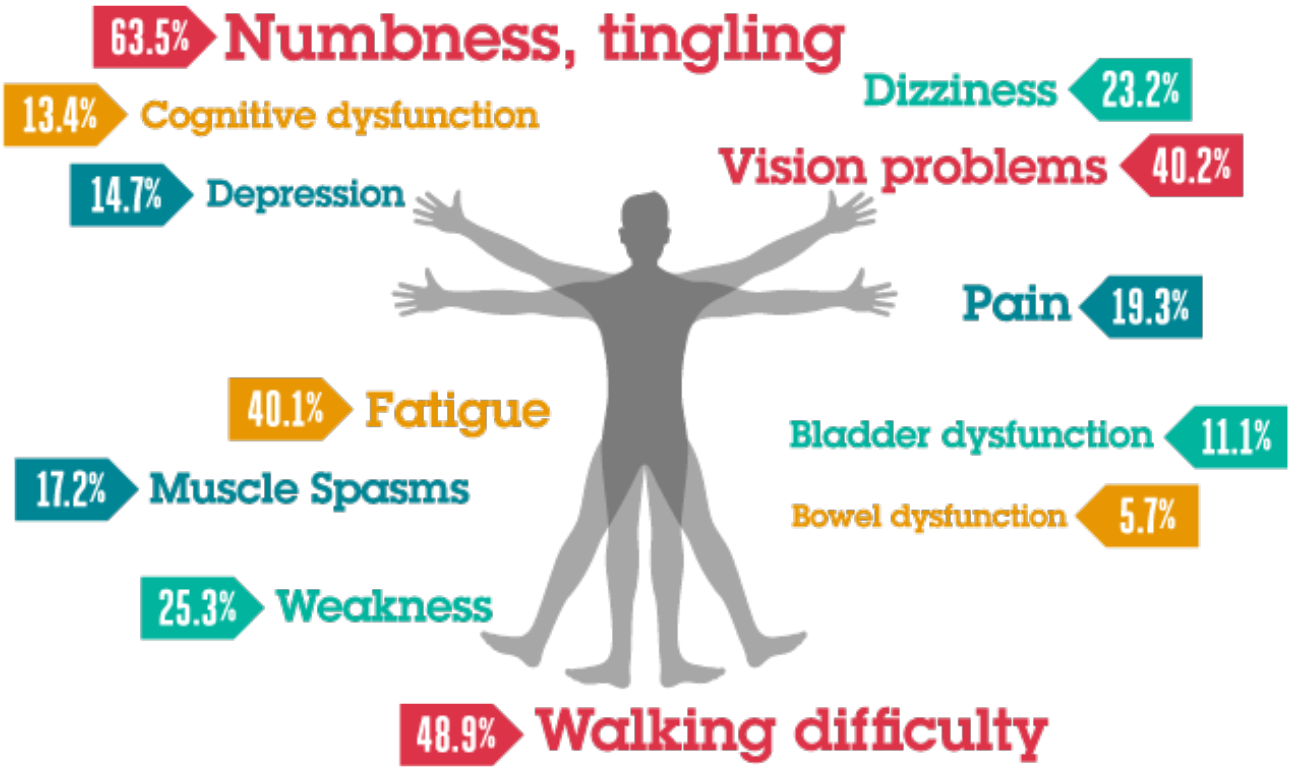

Fig. 3. The proportion of patients that display certain symptoms of multiple sclerosis. Source: http://www.sclerosistreatment.com/2014/01/early-signs-of-multiple-sclerosis.html

Microglia

Recent evidence suggests that microglia, the focus of Prof. Dr. Prinz's laboratory, play a key role in the development of MS. Traditionally, microglia have been seen to be the primary immune defence cells of the central nervous system that respond to foreign pathogens. It is now known that they are wide-ranging and complex in their function, their actions often being context-dependent.

One of these functions is involved in the progression of MS and can be seen in animal models of the disease. As the myelin around neurons degenerate, remnants of the now degenerated myelin remain in the vicinity. New myelin cannot replace the degenerated myelin until the myelin debris is removed. Microglia play a central role in 'eating' the myelin debris surrounding neurons after demyelination, enabling new myelin to wrap around the neurons once again (Neumann et al., 2009). This remyelination is of the interest of many research teams – if remyelination is successful, there is potential for the symptoms of MS to be ameliorated. Microglia, and their role in facilitating remyelination, is therefore a topic of research interest.

Gut bacteria

The last decade has seen an explosion of research into foreign bacteria that reside in the intestines. Nearly 10^{14} bacteria live in the human intestine and are composed of nearly 1000 species (Gill et al., 2006; Qin et al, 2010). These gut bacteria play a critical role in our digestive system – they break down carbohydrates and fibre that are otherwise indigestible, synthesise vitamins, and produce short-chain fatty acids that we absorb (O'Hara & Shanahan, 2006). Gut bacteria are, whist foreign residents of the body, indispensable contributors to our well-being.

Recent evidence shows that gut bacteria have been shown to also affect the central nervous system. Their contribution to brain function is not perhaps their primary role, and is thus an interesting avenue of investigation. Gut bacteria have been reported to affect levels of growth factors in the brain, growth rates of new cells, and even behavioural changes in animal models (Bercik et al., 2011; Berer et al., 2011; Ogbonnaya et al., 2015). Perhaps the most pertinent study related to my research aims is one conducted in 2015 in Prof. Prinz's laboratory, showing that the density of microglial cells in the brain (specifically, the cortex) are affected by gut bacteria (Erny et al., 2015). Specifically, the absence of gut bacteria seems to result in brain microglia increasing in density and adopting an immature state, which impair their ability to carry out their usual functions. Gut bacteria of reduced diversity also show similar results. Interestingly, the effects of the absence of gut bacteria seem to be temporary – as soon as gut bacteria are restored in the intestine, the microglia assume their normal structure and function. The study also found that short-chain fatty acids (SCFAs) may be a key mechanistic player in how gut bacteria exert its effects on the body.

Indeed, for gut bacteria to influence the brain, there must be some form of communication between the bacteria in the gut and the central nervous system. This communication pathway has been recently coined the gut-brain axis.

The gut-brain axis

There are many hypotheses as to how bacteria in the gut can communicate with, and therefore influence, cells in the brain. Given its central role to the human condition, the brain is a very well protected organ of the body. It is not only structurally protected from physical insult by the skull, but entry into the brain from other parts of the body is highly regulated and selective. The 'blood brain barrier' isolates the brain environment from the rest of the

body; a beneficial characteristic in the case of disease. For example, the brain is said to be immune-privileged, as potentially harmful inflammatory responses do not occur in the presence of invading pathogens, as is the case in other parts of the body.

It is therefore all the more significant that gut bacteria, which reside so very far from the brain, have the ability to affect cells within the brain. There are several hypotheses as to how communication between gut bacteria and the brain takes place. Some suggest the vagus nerve plays an important role, as it is a direct neural connection between the gut and the brain and central to regulating intestinal movements (Bravo et al., 2011). Others have identified molecules unique to the gut bacteria ('microbial-associated molecular patterns'; MAMPs) or bacterial by-products such as short-chain fatty acids as possible mechanistic players in the gut-brain axis (Khosravi et al., 2014). Some studies have demonstrated that the blood brain barrier is compromised when bacteria in the gut are disrupted (Braniste et al. 2014). As such, there is a wide variety of hypotheses as to how gut bacteria can exert influence on cells of the brain.

Of particular interest is the notion that communication along the gut-brain axis is mediated by other organs of the body. It is not unreasonable to expect that gut bacteria impacts other organs that are more closely associated with the gut – indeed, the reported changes in the brain may be secondary to other effects in the body. In order to better determine the key mechanistic players along the communication pathway between the gut and the brain, the impact of gut bacteria on other relevant organs in the body can be investigated. For example, the liver receives 70% of its blood via the gut (Son et al., 2010) – should the gut bacteria be influencing the brain via the bloodstream, the liver is likely to play a key role. Given that microglia, the immune defence cells of the brain, are affected by gut bacteria, it is likely that other immune organs of the body (such as the spleen) are similarly affected. My project investigated the role of these bodily organs in the gut-brain axis, and how they contribute to the communication pathway that enables gut bacteria to so readily affect microglia in the brain.

Aims and hypotheses

To address this question, an initial screen of organs of interest was undertaken prior to my arrival in Prof. Prinz's laboratory. Microglia are cells exclusive to the brain, and therefore cannot be seen in other organs of the body. Instead, cells related to microglia found in other

parts of the body, termed macrophages, were investigated due to their similarity to microglia in origin, form and function. Trends towards changes in macrophage density in the liver and the spleen were seen, however due to a low sample size, these changes were not statistically significant. After optimising the technique used to investigate cell density in these organs, I set out to investigate whether these potential changes density were in fact significant and, if so, functionally relevant to the organ in question.

This research question led to the following hypothesis and aims for my research stay at Prof. Prinz's laboratory as part of the AGA Fellowship:

> *Hypothesis I: Gut bacteria affect other organs around the body, which play a mechanistic role in the communication pathway between gut bacteria and the brain.*
>
> Aim: To investigate changes in macrophage density in the liver as a result of removing gut bacteria from the body.

My specific experimental aims aside, the AGA Fellowship provided opportunities for broader professional aims. The globality of the biomedical research community allows for bilateral relations between Australia and Germany to be strengthened through the medium of science. My visit allows me to connect with leading neuroscientists in Germany, and to compare and contrast the research sector in our respective countries. With this insight, I hope to better understand how the research environment can be more conducive to international collaborations. Forging such ties on an international level will not only improve relations between Australia and Germany through science, but will also accelerate the advancement of science and medicine in our lives.

Laboratory methods

My aim was to investigate the effect of gut bacteria on macrophage cell density in the liver. One method to draw such conclusions is to eliminate the gut bacteria completely from the body, and to compare the cell density in the livers of these bodies to those of livers in which gut bacteria were *not* eliminated.

For our purposes, we use mouse models in which the mice are bred in a sterile environment. In this way, these mice are completely free of bacteria from birth through to adulthood. These "germ-free" (GF) mice models are used commonly by research groups that investigate gut bacteria. The influence of gut bacteria is determined by comparing GF mice with standard laboratory mice.

Determining the cell density of macrophages in the liver

In order to determine density of macrophage cells in the liver, we need to count the number of macrophages within a pre-determined area. For this, we need to be able to visualise these cells. A well-established protocol to visualise cells is the staining of cells. The staining process is cell-specific, so that only the cells of interest, for example macrophages, will be visualised.

GF mice and standard laboratory mice were sacrificed and perfused to replace their blood with a clear fixative solution (this enables cells to be better visualised). Samples were taken of the brain and other organs (including the liver) and embedded in paraffin wax. Thin sections of the brain and other organs were cut and mounted onto microscope slides. These cells were then specifically stained such that the macrophages were visible. Images were taken on a confocal microscope and then analysed to determine the cell density of the samples. Macrophage cell densities from GF mice and standard laboratory mice were then compared.

Results

Prof. Prinz's laboratory has already shown that the density of microglia in the brain is increased in the absence of bacteria in the gut (Erny et al., 2015). Similar to the aforementioned research methods, a GF mouse model was compared with standard laboratory mice to determine the influence of gut bacteria. As our research aims are building upon these previous results, it is important for us to replicate the result found in the brain, before further exploring other organs of the body. This enables meaningful conclusions to be drawn regarding the gut-brain axis should we see changes in cell densities in other organs. We could indeed replicate the results previously published, confirming that our cohort of GF mice exhibits similar increases in microglial cell densities in the brain.

The density of macrophages in the liver were then investigated. Upon comparing macrophage numbers between GF and standard laboratory mice, we found a trend towards lower macrophage densities in the liver of GF mice (Fig. 4).

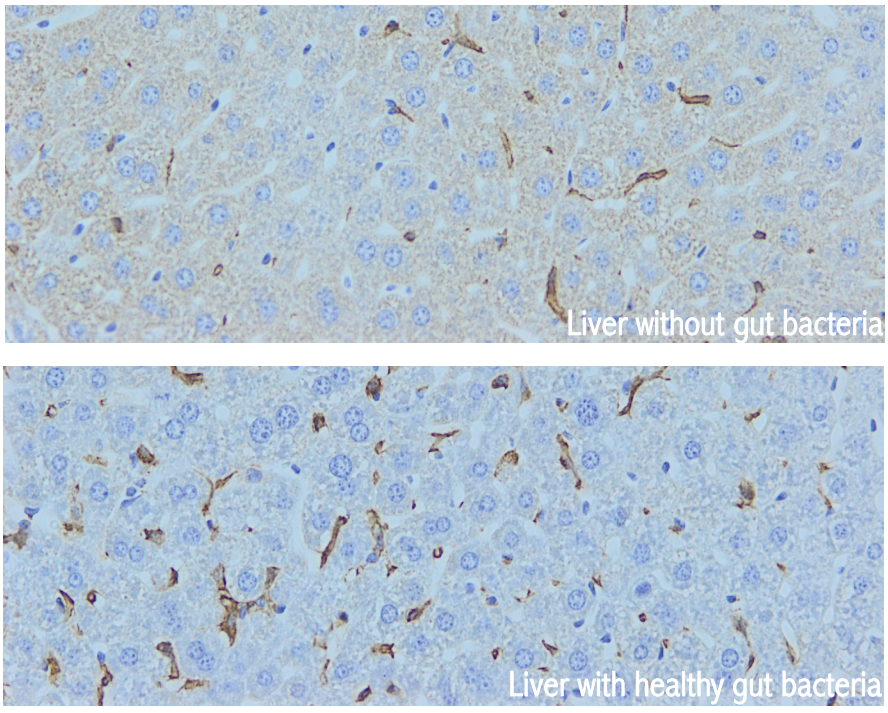

Fig. 4. Germ-free mice lacking gut bacteria (upper panel) display fewer macrophages in the liver compared to standard laboratory mice (lower panel). Macrophage cells can be visualised and counted due to their brown stain.

Interestingly, the lower density of macrophages seen in Fig. 4 was more pronounced in males than in females.

As exact quantifications of the entire cohort of mice are yet to be published by the laboratory, the results described here remain purely qualitative.

Discussion

The AGA Fellowship has provided me with a unique opportunity to undertake a research project in an esteemed neuroscience laboratory in Freiburg, Germany. In doing so, I could apply the expertise of Prof. Prinz's laboratory in microglia to the context of MS, the main focus of our research laboratory at the FINMH in Melbourne. Applying scientific knowledge to different contexts provides potential for previously unexplored research directions to be taken.

The foundations of the research project continue to build on knowledge in the field regarding the role of gut bacteria in the human body. Their impact on the brain is of particular interest, given the traditional view that the brain is otherwise better protected from external influences than other systems in the body.

Results from this project suggest a trend towards a lower macrophage density in the liver of GF mice lacking gut bacteria. Macrophages play a similar role in the body as microglia play in the brain; namely, a role in immune defence that respond to foreign pathogens. The density of macrophages is, however, not necessarily an absolute indicator of immune strength; more relevant is the functional capacity of the cells in the immune system.

Our results support the initial trends that were observed previously by Prof. Prinz's laboratory. They also confirm the work by two other laboratories which similarly demonstrate a significant reduction in macrophage density in mice lacking gut bacteria (Corbitt et al., 2013; Khosravi et al., 2014). One team, however, reported no difference in liver macrophage density between GF and standard laboratory mice (Zhang et al., 2015). Differing results from different laboratories perhaps demonstrates the sensitivity of the germ-free mouse model. The GF mice must be raised in sterile conditions, and the mouse housing must remain sterile throughout life – many laboratories do not have such sterile facilities, and must therefore import these mouse models from elsewhere. During transport, the GF mice may experience varying levels of stress, as well as potentially acquiring an infection – which will detrimentally impact an already compromised immune system.

Our results raise for us two questions. Firstly, how exactly are the gut bacteria affecting macrophages in the liver? And secondly, whether these changes in the liver form part of the communication pathway between the gut and the brain, i.e. the gut-brain axis?

How are gut bacteria affecting macrophages in the liver?

The liver receives 70% of its blood supply via the gut (Son et al., 2010). This fact alone raises the possibility of the bloodstream providing the mechanistic link between the gut and the liver. Indeed, gut bacteria are known to produce a variety of bacteria-specific molecules which are absorbed into the bloodstream. These include short-chain fatty acids (SCFAs) and microbial-associated molecular patterns (MAMPs; Khosravi et al., 2014), which are unique to bacteria and cannot be produced by our own body. These molecules would then reach the liver via the bloodstream, and have the potential to cause the changes we observed in the liver; perhaps the lack of these bacterial factors in the blood has led to the uncontrolled proliferation of macrophages in the liver, resulting in the trend towards an increase in macrophage density that we observed. Further experiments in Prof. Prinz's laboratory are underway to better understand the role of molecules such as SCFAs in the gut.

Is the liver the mechanistic link in the gut-brain axis?

It is difficult to conclude whether the liver provides a key communication tool by which the gut can influence the brain. Indeed, the effects of gut bacteria on the liver may not be cause of the observed brain changes, but rather an effect or a consequence. Several years of research ahead is required before definitive conclusions can be drawn regarding the exact mechanisms by which gut bacteria influences the brain and other organs of the body. We have only utilised one parameter to investigate differences in liver macrophages, namely their density within a given area. Perhaps a more important observation is the analysis of their function as immune cells. This can be done by measuring the presence of certain factors in these cells that are known to be important to carry out their immune function; a technique termed flow cytometry. Further, the exact structure of the macrophage cells can be analysed using 3D reconstruction technology, as the shape and branching of cells often indicate their functional state. These further experiments are currently being conducted by Prof. Prinz's laboratory, and will shed light onto whether the decrease in macrophage density in the liver also results in functional changes.

Given the aforementioned signalling factors SCFAs and MAMPs, that are released by gut bacteria and absorbed into the bloodstream, the liver may prove to be an ideal model from which to understand how gut bacteria affect internal organs. Indeed, the blood circulatory

system reaches every organ in the body, and provides an ideal transport system for signalling factors. One research team has reported the breakdown and dysfunction of the blood brain barrier in mice lacking gut bacteria, which otherwise forms a highly selective barrier to entry into the brain region from the bloodstream (Braniste et al. 2014). As such, signalling factors from gut bacteria may indeed be able to penetrate the otherwise immune-privileged brain.

Impact and relevance to MS

Microglia cells in the brain are an essential component of the immune system in the brain. They therefore are critical in the progression of MS and potential therapies for the disease. Microglia play an important role in clearing cell debris after the demyelination observed in MS patients, allowing remyelination to take place. This feature of microglia is of particular interest to our laboratory at the FINMH in Melbourne.

The fact that gut bacteria affect microglia in the brain is especially novel given the high level of protection afforded to the brain. How gut bacteria achieve this feat is of the interest of many research groups - if we can identify how gut bacteria influence microglia, perhaps we can also modulate the function of microglia using drugs and other therapies. Can we adopt the same tactics that gut bacteria use to gain access to the microglia in the well-protected brain? Modulating microglia function may lead to new directions in generating new myelin in MS patients, and thus fresh insights into ameliorating their debilitating symptoms.

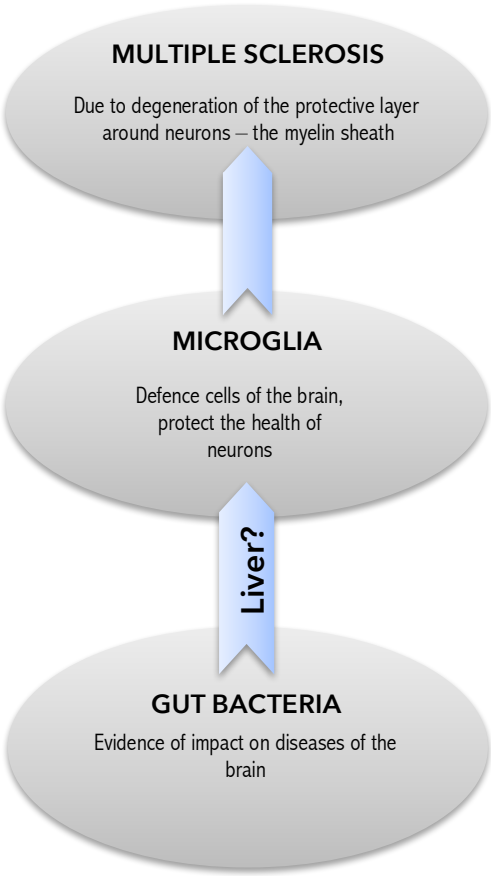

Fig. 5. Microglia help to clean up cell debris after the degeneration of the myelin sheath seen in MS patients. Gut bacteria may play a role in augmenting microglia function, and the liver may be part of this communication pathway, the 'gut-brain axis'.

Conclusions

During my 10-week stay at Prof. Prinz's laboratory at the Universitätsklinikum Freiburg, I succeeded in building the foundations of our project investigating the channels through which gut bacteria can affect the brain – and thus their implications in brain diseases such as MS. We found trends towards a lower density of liver macrophages in mice lacking gut bacteria, and further experiments by the laboratory will shed light on the functional significance of this result, as well as the role of the liver in the context of the gut-brain axis.

I returned home to Australia with fresh insights into microglia form and function, the expertise of Prof. Prinz's laboratory in Germany, which is proving relevant to our research conducted at the FINMH in Australia.

Further, my experience in the biomedical research sector in Germany has allowed me to compare and contrast the research and development systems in Australia and Germany. Scientific research flourishes with meaningful collaborations across disciplines, and geographical borders should be no hindrance. There exists a host of philanthropic organisations, including the AGA Fellowship program, which provide opportunities for forging new scientific directions together. Indeed, science is an apt medium through which Australian-German relations can be strengthened and developed. This is also the view of the Australia-Germany Advisory Group, where the exchange of human capital in science and innovation were noted as recommendations for Australia and Germany to improve their already warm relationship:

> *„The Group highlighted the importance of creat[ing] the foundation for future research collaboration [...] and appropriate funding mechanisms to facilitate intensified scientific exchange".*
>
> *„The Australia-Germany Advisory Group recommends intensifying ongoing and sustained conversations on science, research, education and training"*
>
> *A Fresh Look at Links between Australia and Germany*, Federal Foreign Office of Germany, 2016.

As such, the research visit afforded to me by the AGA Fellowship aligns with the long-term goals of the Australia-Germany Advisory Group in strengthening research collaborations in science.

My experience in Germany as a result of the AGA Fellowship has shaped my professional career directions. I am now currently completing further postgraduate study in Germany, and hope to continue to contribute to collaborative research links between Australia and Germany in biomedical science.

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