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Expanding frontiers for microsporidia: A tribute to Professor Elizabeth U. Canning

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1. Introduction

It is an extreme pleasure and honor to have been selected to present the Founders Lecture in recognition of Professor Elizabeth U. Canning. The Society for Invertebrate Pathology Founders' Lecture Honoree is an individual who is considered to have made such meritorious contributions to the science of Invertebrate Pathology that he/she has significantly influenced the origin, direction, recognition and science of Invertebrate Pathology as a distinct discipline. Professor Canning is first a special scientist and also a special person who has had a tremendous and long lasting impact on science in diverse areas, and we are here today to honor her for her many, many contributions to Invertebrate Pathology (Fig. 1). Excellence in research and teaching are found only rarely in the same individual and numerous former students have stated that there was no instructor at Imperial College who earned greater respect and affection from the students. I had tremendous respect for Liz when I began preparing for this presentation and even more now that I have examined the full scope and breadth of her fabulous career in parasitology.

Liz has been a long standing member of the Society for Invertebrate Pathology and an active member of the Division on Microsporidia. She has served as Chair of the Division and has been a regular participant at annual meeting as well as International colloquia. It took a bit of work but I was able to obtain this image from Dr. Wayne Brooks of Liz with some very recognizable colleagues at the 11th annual meeting of the Society for Invertebrate Pathology and the International Colloquium on Invertebrate Pathology held in 1978 in Prague (Fig. 2). Late night discussions on microsporidia over a few libations in someone's dorm room has been a tradition for many years and one such events is captured here. Seated to the left of Liz are Joe Maddox, Ann Cali, Brian Federici and Liz's student Barbara Pilley. It is clear that this is truly a happy group of pathologist at this impromptu gathering and while there appears to be a bit of cheese remaining on the table, the bottles are empty and a good time appears to be had by all.

I first met Liz while still a student at the 1983 SIP Annual Meeting held at Cornell University in Ithaca, NY. At that meeting I recall another late night session where Ed Hazard, Joe Maddox, Wayne Brooks, Brian Federici, Terry Couch and Liz were discussing various topics over libations (as I recall Scotch Whiskey and Bourbon). As a listener only, I was struck with the comradery among these scientists and at that time knew that I wanted to be part of this group. I have had the great pleasure of attending other Society meetings with Liz over the years and I have always been impressed with her professionalism and the respect she receives from her peers.

Liz began her academic career following her father's footsteps at Imperial College, London specializing in Parasitology for her B.Sc. Degree in Zoology. She continued her studies at the London School of Hygiene and Tropical Medicine for her doctorate degree and felt fortunate to be supervised by two eminent Professors H.E. Short and P.C.C. Garnham. Professor Garnham in particular has a great influence on Liz instilling his philosophy on her that even an insignificant parasite that presented itself as an object of study could open up avenues of research that could lead to important discoveries on parasites of medical, agricultural and veterinary importance. This philosophy is as applicable today as it was then and this morning I will show how the research conducted by Liz has verified this philosophy. Professor Garnham became a lifelong friend of Liz and after his retirement became a senior research fellow

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Fig. 1. Professor Canning at the NATO Advanced Research Workshop 'Emergent Pathogens in the 21st Century: First United Workshop on Microsporidia from Invertebrate and Vertebrate Hosts' held in České Budejovice, Czech Republic, 2004.

Fig. 2. Late night discussions on microsporidia over a few libations at the Eleventh annual meeting of the Society for Invertebrate Pathology and the International Colloquium on Invertebrate Pathology held in 1978 in Prague. Seated to the left of Professor Canning are Dr. Joe Maddox, Dr. Ann Cali, Dr. Brian Federici and Barbara Pilley.

at Imperial College and occupied a lab next to Liz for many years (Fig. 3).

After obtaining her doctorate, Liz was appointed to an assistant lectureship at Imperial College in a newly established section of Parasitology. Liz established her own laboratory of Protozoology and gained an international reputation based on her elegant research work. She was very active in the Society of Protozoologist and successfully

Fig. 3. Professor Canning with Professor John Baker, Professor Keith McAdam and Professsor Garnham in the meeting room of the Royal Society of Tropical Medicine & Hygiene, known as "Manson House" at a British Society of Parasitology meeting. Professor Garnham was Professor Canning's supervisor for her Ph.D.

worked to establish the Protozoological Abstracts and these proved to be an invaluable aid to literature research at the time. Liz steadily climbed the academic latter through promotions to lecturer, reader and full professor and taught generations of students until her retirement in 1993. Before I discuss some of her research accomplishments, I need to say a few things about Liz as a teacher and mentor for her students. She prepared and planned her lectures as carefully as she conducted her research and presented these with extraordinary clarity and detail. She rapidly learned the newest technologies and applied them to both her teaching and research including electron microscopy, immunology and molecular biology often leading the field in applying these to the study of parasitic protozoa. Liz continuously broadened her knowledge and was able to communicate this to her students and incorporate them into her research projects, many conducted together with her students.

As mentioned, Liz has had many students and colleagues throughout her career and there are recurring themes to their comments when asked about Liz. There is of course great respect for her scientific contributions and recognition that her expertise on the biology, life histories, ultrastructure and taxonomy of microsporidia and other protists have had a huge impact on the field of parasitology in general and specifically for the microsporidia. All state that Liz is an absolutely delightful lady to work with, is a patient teacher and that her insightful ultrastructural interpretations are second to none and her written English is perfect.

Aside from her scientific achievements, her students and colleagues consistently comment on how generous and compassionate Liz is with her time and expertise whether it was interpretation of ultrastructure based studies or to conduct field studies and that she is always rigorous and disciplined in her approach to science. Liz was always ready to take students to the field and many were impressed with her enthusiasm for field work even if it meant working under

difficult conditions. She taught her students the value of attention to detail, accuracy, persistence as well as independence. She was always available to provide advice but as one student indicated she didn't 'molly coddle' her students knowing that at some point they would have to make it on their own and she is certainly left with an impressive legacy of students many of whom are now leaders in their respective fields.

A few things that you may not know about Liz. The atmosphere in her lab was always excellent and several students and colleagues have mentioned the readiness of Liz to celebrate when a paper was accepted or a grant awarded. She always had bottles of wine and 'constructable' plastic wine glasses in her filing cabinet for such occasions! Liz is also described as a compassionate person who was a great animal lover who kept cats, two of which I am told were named after 'quality UK carpets' of all things-Wilton and Axminster. As described to me by one of Liz's students, she believed that "her love of these cats—and a dog that came to work with her and slept under her desk, demonstrates the softer side of a very strong, independent, single minded, intelligent and successful academic. She's a great lady who was successful at a time when female researchers were even rarer than they are now. She is a role model for many of us and she strongly deserves the honour that the Society for Invertebrate Pathology has bestowed on her".

Liz also loves to drive sports cars. Several of her students were impressed that she drove a Triumph TR7 and one student commented that trips into South Kensington in the TR7 to help demonstrate in practicals was always fun. After the TR7 it was a red convertible BMW and I remember Dr. Joe Maddox remarking that when he arrived in London to visit Liz he was pleasantly surprised when she arrived to pick him up at the airport in the red BMW convertible. Also, Liz has become an avid golfer and as I understand plays regularly with a group of close friends. I can recall on a visit Liz made to my lab and home in Gainesville, Florida, one of our missions was to track down a particular type of golf shoe.

2. Professor Canning's research

Liz's interests in Protozoa have been broad and covered microsporidia, gregarines, coccidia, malaria parasites and babesias. There were also a few studies of typanosomatids and one on amoebae. Many of the projects involved overseas collaborations with colleagues in a number of countries including Australia, the Czech Republic, France, Holland, Japan, Portugal, Switzerland, and the United States. Liz has published nearly 200 scientific papers in peer-reviewed journals on a wide range of parasitic protozoa. The majority of the papers are multi-authored: Liz has always been generous in including students, assistants and colleagues as co-authors and her name often appears far down the list when it could have been the first.

Liz's dominating research interest has been with the microsporidia. She has investigated microsporidia in a broad range of hosts including locusts, mosquitoes, sandflies, black flies, stored product beetles, trichopterans, various lepidopterans, copepods, trematode larvae and vertebrates. While Liz has worked on many different aspect of parasitology and it would be impossible to cover all aspects of her remarkable research career, I want today to highlight her contributions to the field of microsporidiology and how throughout her career she has continually expanded the frontiers of this fascinating group of organisms.

Liz began her career when a chance microsporidial infection in a colony of locusts provided the material for her Ph.D. studies. Liz recalls an incident when she collected 1500 hoppers and on her way to the London School dropped the tin while crossing the road in a big London square. She held up the traffic while scrambling to collect as many of the fast disappearing hoppers as possible before they reached the grass in the center of the square. Fortunately, the London climate was not conducive to the survival of the many escapees.

In her first publication, Liz provided a detailed description that led to the formal naming and establishment of *Nosema locustae*, which only very recently has been transferred to the genus *Paranosema* (Canning, 1953; Sokolova et al., 2003). In this classic publication, she prepared a detailed diagram of the developmental cycle of *Paranosema locustae* and demonstrated that early in her career Liz was a meticulous researcher who paid great attention to detail. I point out that this study was conducted at a time prior to electron microscopy and other modern methods which made her interpretations even more impressive. She followed this early work with several additional papers on *P. locustae* one of which provided additional details on the developmental cycle (Canning, 1962a) and an important study on the pathogenicity of *P. locustae* for locust (Canning, 1962b) where she documented and detailed the mortality effects in locust infected with *P. locustae*. While to some this may have been an interesting but obscure pathogen, it was noticed by Dr. John Henry who initiated a project in the 1970's at the USDA/ARS Rangeland Insect Laboratory in Boseman Montana to investigate pathogens for control of grasshoppers. Based on the work conducted by Liz, *P. locustae* was selected for intensive development because it infected a wide range of orthopteran hosts (infects about 90 different species of grasshoppers) and was rather easily and economically produced in vivo. Extensive testing was conducted against mammals, birds and fish without any significant effects. These efforts led to the successful registration of *P. locustae* by the US Environmental Protection Agency in 1980, and it is the first and only microsporidian pathogen registered as a microbial insecticide (Henry and Onsager, 1982).

In vivo production in grasshoppers produced spores that could be formulated for application onto grasslands. In fact there is still a commercially available product, NOLO that

can be purchased today. This leads back to the philosophy of Professor Garnham that even an insignificant parasite that presented itself as an object of study could open up important avenues of research as clearly evident by the work of Liz on *P. locustae*. But this story continues to grow as *P. locustae* is currently the object of a large sequencing project to expand our knowledge of the genomes of insect microsporidia. The impact of the early work by Professor Canning on *P. locustae* has led to important research and development and clearly expanded the frontiers of microsporidiology in many important ways.

At the time of her Ph.D. studies, 31 genera of microsporidia had been named, only 15 of which were well known. A review of microsporidia in 1999 cited 144 genera to which a further 15 have since been added. Of the total, Liz and colleagues have established 8 genera and 26 species. Liz has produced a book (with Professor Lom) entitled "The Microsporidia of Vertebrates" (Canning and Lom, 1986) and a number of chapters on the microsporidia and several important monographs. Her book on The Microsporidia of Vertebrates is yet another example of leading the field in this area of microsporidiology and this tomb has remained one of the main reference volumes on the topic. This book also brings to mind something Liz once told me about studies she conducted on a microsporidian species found in toads in England (Canning and Elkan, 1963; Canning et al., 1964). This microsporidium was mainly localized in the muscle and after careful surgery on the toads to remove infected tissues for study, rather that destroy the host, Liz would carefully suture the animal closed and release them back into the environment. She has always demonstrated a great respect for all of the organisms that have been the focus of her research.

Her monograph on "The microsporidian parasites of Platyhelminthes: their morphology, development, transmission and pathogenicity" is another example of her thorough and meticulously detailed characterization of this important but poorly known group of organisms (Canning, 1975). She presented detailed life cycle summaries which she prepared with great attention to detail. While much of her work dealt mainly with life cycles, ultrastructure and pathogenicity of microsporidia in invertebrates, the emphasis shifted towards phylogenetic relations of species, including those in vertebrates. The genera *Glugea* and *Pleistophora* infecting fish were redescribed and the latter was split, with one new genus being established (Canning and Nicholas, 1980; Canning et al., 1982; Canning and Hazard, 1982). This emphasized that the microsporidia in vertebrates and invertebrates that were superficially similar in being multisporous in sporophorous vesicles, were nevertheless phylogenetically unrelated.

My first knowledge and recollections of Liz and her studies on microsporidia were from my early work with Ed Hazard when at that time he had just co authored the paper with Liz in 1982 on the "Genus Pleistophora an assemblage of at least 3 genera" (Canning and Hazard, 1982). This was an extremely important work as it established the term "sporophorous vesicle" for the spore containing vesicle in the microsporidia but it was also my first introduction to the difficult and confusing terminology of the microsporidia. I studied this paper in great detail and recall how carefully and clearly Liz presented this information and also the exquisite electron micrographs used to explain the important distinctions between the "merontogenic sporophorous vesicle and the sporontogenetic sporophorous vesicle". While these terms may mean little to those that do not study microsporidia, this paper by Liz established goals for me as a young scientist to try and follow her lead in presenting clear and well documented studies that would stand the test of time. Professor Canning's many studies have clearly stood the test of time and she is still an inspiration to me to always pay special attention to detail and accuracy in what ever I do.

Eventually, attention was drawn to the microsporidia infecting man. The AIDS epidemic revealed their previously unsuspected common occurrence and the ability of microsporidia to cause potentially fatal diseases when the immunity of the patient was compromised. Research was directed towards diagnosis and treatment, the latter being facilitated by the development of in vitro cultures. Although not involved with the discovery of *Enterocytozoon bieneusi*, the microsporidium most commonly found in AIDS patients, Liz worked with Dutch colleagues on the identification of *E. bieneusi* in Giemsa stained smears (van Gool et al., 1990; van Gool et al., 1993) and with Jiri Vavra on an evaluation of Calcofluor White as a fluorescent dye for easy identification of microsporidian spores by light microscopy (Vavra et al., 1993).

A very productive period of research followed in studies with Waffa Hollister on the in vitro culture and antigenic characterization of microsporidia from AIDS patients (Hollister and Canning, 1987; Hollister et al., 1993). Significantly, a new genus and species, *Trachipleistophora hominis*, was formerly described from human muscle and was grown in culture and biochemically characterized (Hollister et al., 1996). These studies were typified by the presentation of exquisite ultrastructural information on this new species from man. This era was followed by another with Sarah Cheney and Nathalie Tristem using sequence analysis of 16S rDNA and RNA polymerase genes in phylogenetic analysis of microsporidia of invertebrate and vertebrate origin (Cheney et al., 2000; Cheney et al., 2001). I participated in one study in a small way by providing spores of the mosquito microsporidium *Vavraia culicis* for use in this analysis and the results indicated that *T. homminis* is most closely related to two species of *Vavraia*, one from a mosquito and the other from the beetle *Vavraia oncoperae* (Cheney et al., 2000). *T. hominis* may well prove to be of invertebrate origin, perhaps transmitted to man by blood sucking insects or other insects groups. This is yet another example of how Liz has continued to expand the frontiers of microsporidiology with this pioneering work and demonstrating the importance of understanding microsporidia in both vertebrate and invertebrate hosts.

And the research of Professor Canning goes on as she continues to make important contributions in various areas of parasitology. One important recent taxonomic contribution has been on the Myxozoa creating a new class and order for parasites of Bryozoans (Canning et al., 2000). Liz has indicated that she is indebted to Paul Nicholas and Alan Curry for their excellent assistance with electron microscopy throughout many of these studies during her career.

3. My research

As is the custom in the Founders' Lecture, I will spend a few minutes discussing some of my research over the years, primarily my work on the microsporidia. My research focus has been on pathogens of mosquitoes and I have worked with many pathogen groups occurring in mosquitoes including the microspridia, gregarines, viruses, fungi, nematodes and helicosporidia. My work on microsporidia has involved mainly taxonomy and life cycle studies. Some of my recent studies have involved investigations on mosquito pathogenic viruses and the helicosporidia (Becnel et al., 2001; Boucias et al., 2001). These virus studies have concentrated on transmission and the biological and molecular characterization of primarily baculoviruses and cypoviruses (Moser et al., 2001; Afonso et al., 2001; Shapiro et al., 2005; Green et al., 2006). I won't discuss this work further here but I will discuss it in detail at one of the cross divisional symposiums tomorrow. Also, I have been fortunate to have participated in some exciting studies with the Helicosporidia in collaboration with Dr. Drion Boucias from the University of Florida. I isolated a helicosporidum species from a black fly in Florida and subsequent studies have shown that these organisms are the first described algal invertebrate pathogens (Tartar et al., 2003).

Today I will focus on the research I have conducted on the microsporidia. I began my journey on the study of microsporida with Ed Hazard in Louisiana with a focus on microsporidia in mosquitoes. With the untimely death of Ed in 1985, I was transferred to Gainesville Florida to continue these studies. This began a very productive and exciting study of microsporidia in mosquitoes resulting in an improved understanding on the developmental stages and mechanisms of transmission of microsporidia. It was at this time that I was introduced and mentored by some of the top researchers in microsporidiology including Dr. Victor Sprague, Dr. Wayne Brooks, Dr. Joe Maddox, Dr. Al Undeen, Dr. Ted Andreadis, and Dr. Tony Sweeney. I was also greatly influenced by Professor Canning as well as Jiri Vavra, Ronny Larson, Ann Cali and Jarslov Weiser. I have had some fantastic ARS colleagues who have been instrumental in conducting these studies on microsporidia including Tok Fukuda, Peg Rotstein and Genie White. I have also had the opportunity with numerous colleagues from many different countries to work on a variety of microsporidia. We have described 2 new classes, 2 new orders, 5 new families, 5 new genera and 20 new species of microsporidia from mosquitoes, black flies, hymenoptera, beetles, locusts, mites and fleas. But most of my research has focused on the life cycles and developmental sequences of microsporidian pathogens of mosquitoes. These investigations have led to new findings on infective processes, transmission, ultrastructural cytology and developmental sequences and stages of microsporidian parasites. This morning, I would like to review this component of my research program.

First, a few comments about the microsporidian spore. The spore is the diagnostic stage of the microsporidia and has a complex and fascinating structure. The characteristic feature of the spore is the coiled polar filament which is anchored at the anterior end. The spore germinates upon the proper stimulus, the polar filament everts to become a hollow tube through which the sporoplasm is injected into the host cell. It is truly a fascinating and unique organism and probably the reason I became addicted to their study.

The status of knowledge on microsporidia in mosquitoes when I began working with the group can be broken into two main categories. Those with simple life cycles that have only one spore type and involve only one host. Examples are *Brachiola algerae* and *V. culicis* (Becnel et al., 2005). Here again, Liz made, as she has done in many areas of microsporidiology, significant contributions to the study of microsporidia in mosquitoes including some pioneering work on *V. culicis* (at that time known as *Pleistophora*) and *Brachiola (Nosema) algerae* as well as others (Canning, 1957; Canning and Sinden, 1973). She was also responsible for establishing two new genera of microsporidia in mosquitoes (Pell and Canning, 1992, 1993).

The life of *V. culicis* is uninucleate throughout development with multinucleate plasmodia formed and eventually sporophorous vesicles containing up to 32 spores. This species is usually transmitted per os from one generation of larval mosquitoes to the next and has a broad host range. It is representative of species with simple life cycles.

The other category included those microsporidia with complex life cycles with up to two spore types (Becnel, 1994). These were only known to occur in the mosquito host with vertical transmission established but horizontal transmission unknown and developmental and life cycles poorly known. Two of the main groups that occurred in mosquitoes at the time and were the subject of my studies were *Amblyospora spp.* and *Culicospora magna.*

For *Amblyospora* spp. two spore types were known, binucleate spores in adults responsible for vertical transmission and meiospores formed in larvae with an unknown function as they did not infect larvae per os. Meiosis was known but the origins of the diplokaryotic stages that occurred in the life cycle and the complete life cycle were unknown. For *C. magna*, only one spore type was known from larvae and it was not a product of meiosis as in *Amblyospora*. The mechanisms of haplosis (going from diplokaryotic stages to uninucleate stages) were unknown and the mechanisms of transmission and the complete life cycle were unknown.

Several events in my research program together with numerous collaborators allowed for some unprecedented advancements in understanding mosquito microsporidia. The first of these was a new microspriidum with a complex life cycle from *Aedes aegypti* that for the first time could be transmitted both vertically and horizontally (Becnel et al., 1989). The second was the work by Tony Sweeney and Ed Hazard to solve the mechanisms of horizontal transmission in *Amblyospora* proving that a copepod intermediate host was involved in this cycle and finally, new studies to resolve the life cycle of *C. magna*.

Studies on the microsporidium from *A. aegypti*, which we named *Edhazardia aedis*, have been instrumental in understanding many aspects of microsporidian development and life cycles (Becnel et al., 1989). We have published a series of papers on various aspects of the biology of this species establishing the main features of the developmental sequences and life cycle of *E. aedis* (Hazard et al., 1985; Becnel et al., 1989; Johnson et al., 1997). Details of its life cycle as it is currently understood are described below and serves as a model system for understanding microsporidia in mosquitoes with applications to understanding complex life cycles of microsporidia in general.

The basic mosquito–microsporidia relationship of *E. aedis* involves two generations of the mosquito host (Becnel et al., 1989). An infected female mosquito transovarially transmits the pathogen to progeny. Here a developmental sequence occurs in the fat body to produce large number of spores which are released into the environment with death of the host. These spores are infectious per os to a new generation of mosquitoes where a complex developmental sequence occurs in infected females to complete the cycle. There are specific tissues involved in each stage of this process as well as specific developmental sequences. Infections are initiated in gastric caeca of larval mosquitoes and is then transferred to larval oenocytes that are carried over into the adult mosquito. Here binucleate spores are formed that infect the eggs. In larval fat body of progeny a developmental sequence occurs to produce spores to complete the cycle. The specific developmental sequences in each of the tissues in the various stages of the mosquito host is discussed below.

Infections are initiated in the gastric caeca of larval mosquitoes by uninucleate spores. A developmental sequence occurs that involves a replication sequence followed by the formation of gametes that fuse to form diplokaryotic stages. These diplokaryotic stages quickly sporulate to form the first or early spore which germinates and transfers the parasite to larval oenocytes (Johnson et al., 1997).

The next developmental phase occurs in larval oenocytes in adults. Replication of diplokaryotic stages fills the larval oenocytes. After a blood meal the stages sporulate to form binucleate spores which are now located near the ovaries. These germinate and deposit sporoplasms into the developing eggs. The next developmental phase occurs in larval oenocytes in adults. Replication of diplokaryotic stages fills the larval oenocytes. After a blood meal the stages sporulate to form binucleate spores which are now located near the ovaries. These germinate and deposit sporoplasms into the developing eggs. In the progeny of infected females, development is restricted to larval fat body. Here two sporulation sequences occur: the functional one involves nuclear dissociation to produce uninucleate sporonts and eventually spores. These are the spores responsible for horizontal transmission to a new generation of mosquitoes to complete the life cycle. In this process, the two nuclei of the diplokaryon separate and results in the formation of uninucleate stages as demonstrated here. These stages sporulate and form the per os infectious spores. These spores are similar to the spores of *Amblyospora* formed in copepods responsible for per os infection to the mosquito host. The sequence that involves meiosis also occurs in the infected larval progeny, is similar to what occurs in *Amblyospora* but it only rarely produces meiospores which do not appear to be functional. It appears that this is a vestigial sequence that no longer plays a role in the life cycle. In *Amblyospora spp.*, the meiospores are responsible for infecting the copepod intermediate host.

Studies on *C. magna* in conjunctions with the *E. aedis* work helped resolve the crucial life cycle features of this species. This life cycle is virtually identical to that found in *Edhazardia* except that there is no evidence of meiosis or meiospores and haplosis is by nuclear dissociation alone (Becnel et al., 1987). This work was followed by a series of studies on several *Amblyospora* species including the type species *A. californica* (Becnel, 1992). These investigations were focused on the specific role of the copepod intermediate host and the initial developmental sequences in the mosquito host using information learned from the studies on *Edhazardia*. Crucial work by Tony Sweeney and Ed Hazard in 1985 proved that the meiospores of *Amblyospora* infects a copepod intermediate host and this was soon verified in studies by Ted Andreadis (Sweeney et al., 1985; Andreadis, 1985). Our studies on the type species verified the role of the copepod intermediate host and established that horizontal transmission to the mosquito host followed the same pattern as seen in *Edhazardia* and *Culicospora*. Therefore, these morphological and life cycle studies established that these mosquito microsporidia with complex life cycles formed a monophyletic group. This relationship was confirmed with molecular analysis is a series of publications with Charlie Vossbrinck and his student at the time Mike Baker (Baker et al., 1997, 1998) and recently with Ted Andreadis and Jiri Vavra (Vossbrinck et al., 2004). This molecular analysis verified the relatedness of the "true" mosquito microsporidia and demonstrated that mosquitoes and their parasites have co-evolved. This same molecular analysis has confirmed that *B. algerae* and *V. culicis* are unrelated to this group of "true" microsporidia from mosquitoes and are unrelated to one another. For the "true" mosquito microsporidia, new groups with complex life cycles will continue to reveal variations and new pathways with a better understanding of the basic mechanisms for host exploitation. Finally, I hope I have made the case that studies of

microsporidia in mosquitoes have provided crucial foundational information that can be applied to the study of microsporidia in a wide variety of host group systems and help resolve important taxonomic and life cycle issues.

4. Conclusion

I will now close with a few additional comments about our esteemed honoree. For Liz's excellence in research she was awarded the Imperial College Huxley Memorial Medal and Prize. Also, a special symposium was held in her honor in 2003 titled "Parasites on phylogenetic boundaries: A tribute to Elizabeth Canning" by the British section of the Society of Protozoologists. The diversity of topics covered by this impressive group of experts in parasitology in her honor is a testament to her outstanding career. In 2004, she was awarded the Purkyne Medal by the Academy of Sciences of the Czech Republic for merit in the field of Biomedical Science. She was also awarded the 2004 Gold Medal of the Faculty of Science of Charles University, Prague presented here by Professor Vavra at the 1st United Workshop on Microsporidia for Invertebrate and Vertebrate Hosts (Fig. 4).

Earlier this year Professor Canning was awarded the highly prestigious Emil Brumpt Prize (held jointly with Dr. Isabelle Desportes) awarded for outstanding research in Protozoology. In a recent speech in honor of Liz for being awarded this prize, Dr Killick-Kendrick had some extremely insightful comments about women in science and with his permission I will relate them to you here.

One of the greatest British scientists of the 20th century gave a recipe for women's success in science. She was the crystallographer Dame Kathleen Lonsdale, one of the first of two women to be elected to the Fellowship of the Royal Society. She wrote: 'For a woman, and especially a married woman with children, to become a first class scientist she must first of all choose, or have chosen, the right husband. He must recognize her problems and be willing to share them. If he is really domesticated, so much the better. Then she must be a good organizer and be pretty ruthless in keeping to her schedule, no matter if the heavens fall. She must be able to do with very little sleep, because her working week will be at least twice as long as the average trade unionist's. She must go against all her early training and not care if she is regarded as a little peculiar. She must be willing to accept additional responsibility, even if she feels that she has more than enough. But above all, she must learn to concentrate in any available moment and not require ideal conditions in which to do so.'

This clearly could have been written about Liz. Her success in reaching the pinnacle of our profession has been due, at least partly, to her incredible industry and the great care she takes in pursuit of her goals. The tenacity of the English is legendary and Liz has always accepted new challenges even when the path has been hazardous and has required crossing many bridges. She has worked with an astounding number of collaborators all over the world who, because she commands their respect and affection, remain her friends for life. But she also has taken time to enjoy her pursuits and has taught us that there is always time for ice cream (Fig. 5). Professor Canning, please rise and I ask all of her many friends and colleagues to help me acknowledge the SIP 2005 Founders' Lecture Honoree.

Fig. 4. Professor Canning receiving the 2004 Gold Medal of the Faculty of Science, Charles University, Prague from Professor Jiri Vavra.

Fig. 5. Professor Canning at the First Congress of Protozoology, Prague, 1961 enjoying ice cream with Norilla Adams on a visit to Karlovy Vary (Carlsbad).

5. Concluding remarks by Professor Elizabeth U. Canning

May I respond to this great honour by plagiarising and misquoting, with due apologies, the famous speech of President John F. Kennedy to the US nation "Ask not what I have done for the Society of Invertebrate Pathology but what the Society has done for me". When I started to work with microsporidia as a Ph.D. student I was completely isolated. There was virtually no one in the United Kingdom with whom I could discuss these organisms. It was recommended to me that I should speak to Annie Porter. Who's Annie Porter you may ask? She was the wife of H.B. Fantham. Who's H.B. Fantham you may well ask? Fantham and Porter together wrote several papers before the First World War on Isle of Wight Disease in bees caused by *Nosema apis*. She was very pleasant but in reality was unable to help. My first real contacts came at the 1st International Congress of Protozoology in Prague in 1961. There I met Drs Vavra and Lom, who were students of the celebrated Professor Jirovec. Both have since become distinguished scientists in their own right and have made significant contributions to the field of microsporidiology.

The real breakthrough for me came, however, at the meeting of the Society of Insect Pathology as SIP was then known, at College Park in 1971. There I met the up and coming scientists in the field and the well-known Victor Sprague. In 1968 he had conceived the idea of a multiauthored volume on the microsporidia. At the meeting Victor allocated to me the systematics of microsporidia parasitizing platyhelminthes amphibians reptiles and mammals. In practice the concept didn't work out like this but I managed to publish the platyhelminth section as a separate review and the rest as a book co-authored by Jiri Lom "The Microsporidia of Vertebrates" published by Academic Press. This remained a reference book until the multiauthored book edited by Murray Wittner and Lou Weiss was published in 1999.

The College Park meeting was significant for me. From then on I was in touch with a wide range of people round the world by correspondence and at meetings, including several of the SIP meetings. I was no longer isolated and benefited from the exchange of views with like minded researchers. From then on the microsporidia have proved to be of unfailing interest and always my favourite parasites. I had always classified myself as a protozoologist, so was somewhat daunted when the microsporidia became allied to the fungi in effect becoming plants and myself a botanist. Microsporidia continue to launch surprises on us.

I would like to thank the nominating committee and Dudley Pinnock in particular for considering me for the Founders Lecture Nominee. I am exceptionally grateful to Jimmy Becnel for his appraisal as Founders Lecturer of my scientific career, with anecdotes from my family life. Jimmy must have spent a great deal of time researching my contributions to Invertebrate Pathology and I am deeply appreciative. Also, may I thank your president Just Vlak for ensuring that I didn't get lost on the way to the platform. Finally, I warmly thank the Society for presenting me with such a magnificently framed and illuminated certificate. It will take pride of place in my home as I am soon to leave my office at Imperial College.

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