

## Ideas and Networks: The Rise and Fall of Research Bodies for Powered Artificial Arms in America and Canada, 1945-1977

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Article abstract

This paper examines the rise and fall of research and development funding programs for upper-limb myoelectric prosthetics in America and Canada from 1945 to 1977. Despite similarities in overall technological goals, to produce electronic arms and hands for veterans in the US and children with phocomelic limbs in Canada, we argue that the reasons for starting and ending the programs reflected different national preoccupations. In the US the reasons for the creation in 1945 and termination in 1977 of funding programs focused on the lack of fundamental research in the field, and role that science could have in the development and design in prosthetics. In Canada, by contrast, there was little discussion about science and its relationship to technology in knowledge creation when the prosthetics research and training unit (PRTU) funding program was founded in 1963 and wound up in 1975. Instead, the policy discussion focused on the importance of regional representation and relationships among different professional groups and sectors of society.

# Ideas and Networks: The Rise and Fall of Research Bodies for Powered Artificial Arms in America and Canada, 1945–1977

David J. A. Foord<sup>1</sup> and Peter Kyberd

**Abstract:** *This paper examines the rise and fall of research and development funding programs for upper-limb myoelectric prosthetics in America and Canada from 1945 to 1977. Despite similarities in overall technological goals, to produce electronic arms and hands for veterans in the US and children with phocomelic limbs in Canada, we argue that the reasons for starting and ending the programs reflected different national preoccupations. In the US the reasons for the creation in 1945 and termination in 1977 of funding programs focused on the lack of fundamental research in the field, and role that science could have in the development and design in prosthetics. In Canada, by contrast, there was little discussion about science and its relationship to technology in knowledge creation when the prosthetics research and training unit (PRTU) funding program was founded in 1963 and wound up in 1975. Instead, the policy discussion focused on the importance of regional representation and relationships among different professional groups and sectors of society.*

**Résumé :** *Cet article examine la montée et le déclin des programmes de financement portant sur la recherche et le développement de prothèses myoélectriques pour membres supérieurs, aux États-Unis et au Canada, entre 1945 et 1977. En dépit de la similitude des objectifs technologiques globaux de chaque programme, consistant en la production de bras et de mains électroniques pour les vétérans de guerres aux États-Unis et pour les enfants atteints de phocomélie au Canada, nous soutenons que les raisons du démarrage et de l'arrêt de ces programmes reflétaient des préoccupations nationales différentes. Aux États-Unis, les raisons de la création en 1945 et de l'arrêt en 1977 des programmes de financement sont à chercher dans le constat d'un manque de recherche fondamentale dans le domaine et du rôle que la science pouvait avoir dans la conception et le développement des prothèses. Au Canada, par contraste, il y a eu peu de discussions sur le rôle de la science et sa relation à la technologie dans la création de nouvelles connaissances, lorsque l'unité de recherche et de formation des prothèses (PRTU) a été fondée en 1963 puis dissoute en 1975. Le débat politique était plutôt axé sur l'importance des représentations régionales dans l'unité et sur les relations entre différents groupes professionnels et secteurs sociaux.*

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**Keywords:** research policy, prosthetics, artificial limbs, Canada, USA

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ROY MACLEOD AND RICHARD JARRELL WROTE in their introduction to a 1993 volume of *Scientia Canadensis* dedicated to comparative histories of Australian and Canadian science that: “The primary questions for the would-be comparative historian are what to compare, and why. Neither is simple to state clearly. The why question is more subtle.”<sup>2</sup> In this paper the ‘what to compare’ is the origin and termination of research and development funding programs for powered upper-limb prosthetics in Canada and US from 1945 to 1977. The comparison shows great differences in the national approaches. Interestingly, the

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methods employed on either side of the border to design and produce the commercial upper-limb myoelectric devices during the period were remarkably similar.<sup>3</sup> In both countries the research and development activities were couched as scientific research, although the projects to create the systems are better described as design engineering and involved what is now referred to as user innovation, given the relatively long period of device testing with users and incremental improvement.<sup>4</sup> There were commonalities in the new knowledge that arose from basic engineering designs, software, and hardware products. The systems all employed myoelectric control systems, electrodes on the skin surface, batteries, electronics, and plastic or rubber coverings. Thus, although there were strong and quite different national preoccupations in science policy and funding in this field, these influences were not determinative of the new knowledge.

To the ‘why’ question, the reason for the comparative study is to examine the extent that these national research and development policies and funding programs were determined by differing national preoccupations. This question is of interest to historians of science and technology such as Thomas Misa whose work has argued for the understanding of technology creation and use within national/regional cultures.<sup>5</sup> It is meaningful for science, technology, and innovation policy communities in exposing taken-for-granted assumptions underneath policy making. There are implications for the international literature on policy convergence.<sup>6</sup> It also contributes to scholarship that has explored themes in Canada-US comparative histories of values and institutions, higher education and technology regulation.<sup>7</sup> This research has examined contrasting styles of regulation in a number of fields, including alachlor, dioxins, farmed salmon, pulp and paper, and radon.<sup>8</sup> Scholarship on technology policy has receive less attention.<sup>9</sup> The University of British Columbia political scientists, Kathryn Harrison and George Hoberg in their paper on regulation of dioxins and radon gas outlined six major forces behind agenda-setting in North American environmental: (i) policy entrepreneurs, whether in government or interest; (ii) media; (iii) science and technology; (iv) cross border influences; (v) government structures; and (vi) culture. There are common forces explored in this paper, in particular the “policy entrepreneurs” at the National Academy of Sciences, cross border influences (moving in both directions across the border), and, most profoundly, culture.

In the case of Canada, the cultural thesis accords with MacLeod and Jarrell’s view that “there is much to be said about the importance of persisting styles, contexts and choices, inherited from the colonial past, which give a particular character to the politics of science.”<sup>10</sup> In Canada the Department of National Health and Welfare’s establishment and then termination of funding for four prosthetic research and technical units (PRTUs) to develop artificial limbs for children with pholecomic limbs reflected longstanding preoccupations with regional representation, the role of a strong central government and productive relationships among regions and these public institutions.<sup>11</sup> In the US, the rise and fall of powered upper limb funding programs occurred in the context of discussions within the National Academy of Sciences (NAS) about the transformative power of science, expansion of the frontiers of knowledge, and its application within industry.

This ‘why’ question is different than the more traditional question that seeks to assess the positions of leaders and laggards in the emergence of science, on the assumption that national science cultures moves through a series of stages taking a nation from scientific dependency to self-sufficiency.<sup>12</sup> In term of the relationship between US-Canadian

scientific cultures, MacLeod and Jarrell's view is that: "The influence of American scientific institutions, education, industry and trade has always had an immediate impact upon Canadian development." Hoberg has likewise argued that for Canadian regulatory policy there is an emulation process at work, largely in response to the diffusion of knowledge from the US to Canada.<sup>13</sup> Although Americans influenced Canadians in the selection of myoelectric powered systems as the best option for powered artificial arms and hands, and the identification of myoelectric signal control as the primary research problem to be addressed in the 1960s, Canadian development of artificial upper limbs was also strongly influenced by Canadian federal government funding programs that moved electrical engineering researchers out of laboratories and into hospitals and collaborative design projects with occupational therapists, prosthetists, and device users. More broadly, this location of inter-disciplinary design projects into clinics proved to be a critical element for projects on both sides of the border that transversed the fuzzy line between pre-commercial and commercial products.

### Background

Although the needs of World War I veterans drove growth in the design of prosthetics in the post-war period, it was not until World War II that governments became active in supporting research. In Canada, the Department of Veterans Affairs was charged with the responsibility to manufacture, fit, and service all prosthetic appliances for veterans in 1916. The department's research mission was not added until 1944.<sup>14</sup> Canada was not alone in these developments. In 1917 the US Surgeon General of the Army called limb makers to Washington to discuss the problem of supplying artificial limbs to veterans of World War I. But only in 1945 did the US National Academy of Sciences–National Research Council organize a sponsored cooperative research and development program to address issues in the field.<sup>15</sup>

The motivation for the new research mission came in part from the International Conference on Amputations and Artificial Limbs, held in Ottawa, and at the Christie St. Hospital, Toronto, in February 1944. It was organized by the Canadian National Research Council and was attended by representatives from the United States, Great Britain, Australia, and the USSR. According to a history of Canadian rehabilitation during the period by National Research Council employee Walter Woods:

[The meeting]...laid the foundations for scientific study of the subject. Arising from this meeting the Advisory Committee on Artificial Limbs, National Research Council, US, the Standing Advisory Committee on Artificial Limbs, British Ministry of Pensions, and the Associate Committee on Artificial Limbs, National Research Council, Canada were formed to direct the study of fundamental data, improvements of materials and development of prostheses.<sup>16</sup>

It was after World War I that the concept of using myoelectric signals in stump muscles for control of a mechanical hand was first demonstrated in a bench-top electric prosthetic hand in Berlin in 1919. However, the use of myoelectric control would have to wait for the end of the next world war. The device was developed by Ronald Reiter during his graduate studies in physics at the University of Munich from 1944 to 1948. The system he designed and built was also a literal bench-top tool due to its dependence upon AC electricity and the size of the vacuum-tube amplifier, similar in size to an attaché case.<sup>17</sup> Although the device used a three-state controller and proportional control as devices do today, it never proceeded to clinical investigation.<sup>18</sup> Reiter stated that in 1948, "the

political and economic conditions in Germany were not conducive to further work on the project.”<sup>19</sup> Although published, the work would only be rediscovered after the initial development of similar myoelectric systems in the 1960s.

As with space rocketry, the most sensational developments of myoelectrically controlled hands in the late 1950s occurred in the Soviet Union. The concept of using electrical signals from muscles to control a prosthesis was formulated in 1957 by a joint group at the Machine Research Institute and the Central Research Institute.<sup>20</sup> At the 1958 World’s Fair in Brussels, the USSR’s pavilion of new technological breakthroughs showcased the myoelectric-forearm prosthesis powered by a miniature DC motor and battery pack worn on the amputee’s belt. The design was to have significant influence in the United Kingdom and Canada, where rights were licensed for manufacturing. Worldwide, it raised expectations about what could be done for amputees and provided fuel for scholarly and popular science articles on the future of the human-machine interface and the field of cybernetics.

### Histories

There has been more written about the rise and fall of upper-limb prosthetics R&D funding programs in the US than in Canada. The consistent view among articles on the origin of US programs is that they were driven by the desire to provide artificial limbs for World War II veterans and the assumption that progress would be achieved by a science-based program. There is less consensus on the reasons for the disestablishment of U.S. programs.

Dudley Childress, a former director of the Prosthetics Research Program at Northwestern University, characterized the period from 1945 to 1965 in the US as driven by US federal government funding programs to address the needs of World War II veterans and to remedy “the relatively primitive nature of prosthetics and orthotics previous to that time.”<sup>21</sup> This was accomplished by not only the commitment of funds to R&D by governmental agencies, but also “the effective coordination of research efforts and evaluation projects brought about by the Committee on Prosthetics Research and Development (CPRD) of the National Academy of Sciences/National Research Council (NAS/NRC).”<sup>22</sup> He underlined the importance of the connection: “The NRC venue was key to the success of the Committee because the NRC imprimatur provided the Committee and its successors with national prominence, recognition, and credibility for the next 30 years.”<sup>23</sup> According to Childress, “by 1965, or thereabouts, many of the fundamental principles currently used in prosthetics had been established. Advancements since then seem to have emphasized technical developments, with less concentration on principles than during the previous 20-year period.”<sup>24</sup> Technical progress occurred through the introduction of new materials, such as thermoplastics and composites, new socket designs, commercial availability of electric powered arm components and myoelectric controls, and computer-aided-design and computer-aided-manufacturing (CAD/CAM). This, according to Childress, was an important part of the undoing of the CRPD and the associated funding for prosthetics R&D in the late 1970s as it allowed the NAS to justify cutting budgets because the work was too development focused and did not emphasize science-based investigation.

Another insider account in the U.S. was written by Robert Gailey, director of the Miami Veterans Affairs Healthcare Systems Functional Outcomes Research and Evaluation Center and a professor at the University of Miami School of Medicine.<sup>25</sup> Like Childress,

Gailey argued it was World War II that drove the creation of government programs and funding for prosthetic fundamental research. In Gailey's narrative, prosthetic research funding dried up from the late 1970s through the 1990s, as the primary cause for loss of limb changed from trauma to diabetes and dysvascular disease, and the funding priority shifted to fundamental research in the new areas as well as prevention of amputation.

A. Bennet Wilson, a former technical director and director of the US National Academy of Science's CPRD, shares with Gailey the thesis that major wars are the stimulus for development of improved prostheses.<sup>26</sup> Likewise, he wrote that the results of this post-war research was responsible "for delineating the basic principles of fitting and alignment."<sup>27</sup> Wilson, like Childress and Gailey, was a participant in the battles over the future of the National Academies of Sciences CPRD and Committee on Prosthetic-Orthotic Education (CPOE) in the 1970s, and so his narrative reflects his experience as an officer of the CPRD. The fall of the organization was a hard blow for Wilson, and as part of the change he resigned his position at the CPRD. Wilson wrote that no new programs were developed for development and commercialization of powered upper-limb products.

One of the few surveyors of the field in both Canada and the U.S. was a Canadian engineer, Douglas Hobson, who like Childress worked in the fields from during the 1960s to the 1990s. He referred to the period from 1945 to 1960 as "The Prosthetics and Orthotics Heyday."<sup>28</sup> Like Childress, his view was that the field was driven by returning veterans with amputations who "created the political and social will to do something to compensate veterans for their tremendous personal sacrifice."<sup>29</sup> He characterized the field, somewhat nostalgically, as rising with the will created first by World War II, the polio epidemic in the early 1950s, the thalidomide tragedy in the 1960s, and finally the Vietnam War.<sup>30</sup> This led to the creation of R&D funding programs delivered by the US Department of Health, Education and Welfare and the Veterans Administration. The key figures in Hobson's narrative are the engineers, technical personnel, and clinical colleagues who worked together in rehabilitation settings.<sup>31</sup>

The fall in Hobson's history came in 1976, when the US Academy of Sciences disbanded the CPRD. According to Hobson, this resulted in decreased levels of interagency and international collaboration in rehabilitation technology. Efforts were made to find another home for the CPRD, but this never materialized as its two main funding partners, the US Department of Health, Education and Welfare and the Veterans Administration, were now focused on the development and support of rehabilitation engineering centres. Thus, while US funding bodies shifted from grant-funding of individual researchers to institutional funding of centres, in Canada, the federal government ended funding for the four research centres at the universities of British Columbia, Winnipeg, Toronto, and New Brunswick in the mid-1970s, and charged the Canadian National Research Council (NRC) with leading in the development of electronic super limbs. The effect, however, was similar in that funding for university-based R&D was cut in both Canada and the United States. The difference is that in the US, the Veterans Administration Office of Research and Development developed internal centres for rehabilitation in New York and Tampa. In Canada, responsibility for prosthetics R&D moved to Ottawa.

David Serlin, an American historian and researcher in the field of disability studies, provides an alternative historical account in two essays.<sup>32</sup> He divides his history into pre- and post-World War II. His central argument is that

the physical design and construction of prostheses help[ed] to distinguish the rehabilitation of veterans after World War Two from earlier periods of adjustment for veterans. Prosthetics research and development in the 1940s was catalyzed, to a great extent, by the mystique of scientific progress. The advent of new materials science and new bioengineering principles during the war and the applications of these materials and principles to new prosthetic devices helped to transform prosthetics into its own biomedical subdiscipline.<sup>33</sup>

To bring plastics and engineering into patriotic service for veterans, the US National Academy of Sciences of the National Research Council, “funded and supported advanced prosthetics research, especially at university and military laboratories.”<sup>34</sup> The first US program into power-driven artificial limbs was announced in late August 1945, two weeks after the war with Japan ended. In Serlin’s narrative, science, engineering, technology, military-industry production techniques, and government funding programs of the 1940s to 1960s were pressed into the service of a larger strategy and cultural preoccupation. He wrote that: “The association between amputees and state-of-the-art prosthetics research may have been an intentional strategy to link disabled veterans with the positive, futuristic aura surrounding military-industrial science.”<sup>35</sup> Why the need for the aura? It was the “postwar preoccupation with masculinity and productivity” and “among other things, the fiercely heterosexual culture of postwar psychology, especially in its orthodox zeal to preserve the masculine status of disabled veterans.”<sup>36</sup> Cultural ideals emerge as the primary force in the project making the damaged male body productive. What Serlin characterizes as “perhaps the greatest conceptual challenge to modern industrial capitalism” was met by the development of prostheses such as the cable-driven hand designed by Henry Dreyfuss for the US Veterans Administration.<sup>37</sup>

In Serlin’s history, the primary force is post-war American culture and the ideal of the masculine, productive, able-bodied man. Science provides its mystique of progress and materials. Clinical research determines the power source, electric, not hydraulic or pneumatic. Engineers and prosthetists, the primary agents of the post-war American cultural ideal, operate in the foreground, practicing their engineering design and construction of devices.<sup>38</sup>

### **Origins in the United States**

In the US, the federal government responded to World War II veterans through the sponsorship of R&D, education and training programs, and conferences. The US National Academy of Sciences discovered that little modern scientific effort had gone into the development of artificial limbs, and in 1945 initiated a “crash” research program funded by the Veterans Administration Office of Scientific Research and Development. The state-of-the-art devices in 1945 were shoulder powered, artificial limbs for adult arm-amputees, using cables to open and close a wooden, mechanical hand. For children, it was cable-controlled hooks, as artificial hands had not been developed in small sizes.<sup>39</sup> One of the major outcomes from the sponsored programs of the Office of Scientific Research and Development came from a project at International Business Machines Corp. (IBM). IBM investigated the concept of an electric arm, and then developed a device with internal financial support and from the US Veterans Administration.<sup>40</sup> From that project came the realization that arm amputees could not control the electric arm without conscious thought, and that for most amputees the level of effort to control a prosthesis exceeded the benefits received. The suggestion was that future research should focus on electric arm control.

The program of the Office of Scientific Research and Development lasted for two years. In 1947, the National Academy of Sciences, on advice from its advisory committee on artificial limbs, set up a new program to fund research at universities and industrial laboratories. This program lasted 30 years, from 1947 to 1977, with a major change in 1955 when the National Academy of Sciences created the Prosthetics Research Board (PRB) to run this program. In 1959, the PRB created two committees, the committee on prosthetics research and development (CPRD) and the committee on prosthetics education and information (later called the committee on prosthetics and orthotics education or CPOE), all of which continued until 1977 when the board and committees were dissolved by the National Academy of Sciences. The CPRD emerged as the major national coordinator of upper limb R&D funding during this period.

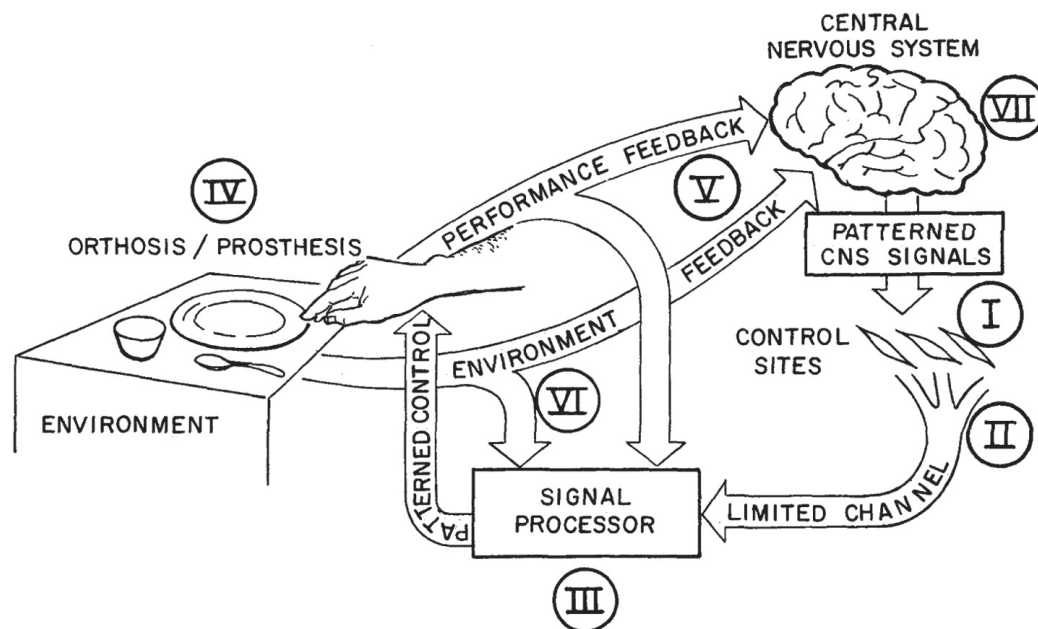
The broad mission of these programs was not just to replace wood with plastic, leather straps with suction-cup sockets, and muscle with batteries and motors, but to understand the human body. The 1962 publication *Progress in Prosthetics* described how modern science would hopefully work on technology from the mid-1940s onwards: “The first decade of this research was of the patient, painstaking basic type which usually precedes dramatic discoveries in science. Now, breakthroughs are in sight which could bring prosthetics fully into step with this new age of electronics.”<sup>41</sup> According to the authors, the process would unfold this way: “Developmental devices and techniques progress through four phases—basic research, model development and evaluation, clinical and field studies, and production by the limb industry.”<sup>42</sup>

As in Serlin’s history, the origins of the externally powered program were founded on the premise that science would show the path of progress. Clinical researchers were expected to sort out the details of power sources. Engineers and prosthetists would design and construct devices. The major difference is that the underlying cultural goal was not the ideal of the masculine, productive, able-bodied man, but the realization of the cybernetic system.

Norbert Wiener conceptualized the human cybernetic system in his 1948 book *Cybernetics: the science of control and communication in the animal and the machine*.<sup>43</sup> The origins of the book were in research Wiener performed during World War II on “predicting the future positions of fast-flying airplanes.”<sup>44</sup> Underlying cybernetics was the observation that the information processing used to determine the position of enemy fighter planes was the same as that which “lay at the root of all intelligent behavior...[such as]...light and heat-seeking movements by plants and primitive creatures; homeostatic processes such as the body’s internal mechanisms for regulating appetite and temperature; and virtually every form of higher-order animal behavior. All those purposeful actions were governed by circular communication processes and guided to their goals by error-correcting negative feedback.”<sup>45</sup> In *Cybernetics*, Wiener addressed the application of cybernetic theory to prostheses. The promise was not just to control a prosthesis, but also to receive sensory-feedback information to further enhance control and prosthesis movement. Wiener wrote:

There are two other fields where I ultimately hope to accomplish something practical with the aid of cybernetic ideas, but in which this hope must wait on further developments. One is the matter of prostheses for lost or paralyzed limbs...The loss of a segment of limb implies not only the loss of the purely passive support of the missing segment or its value as mechanical extension of the stump, and the loss of cutaneous and kinesthetic sensations originating in it. The first two losses are what the artificial-limb maker now tries to replace. The third has so far been beyond his scope





**Figure 1:** Element of Prosthetic or Orthotic System. Ames B. Reswick and Lojze Vodovnik, "External Power in Prosthetics and Orthotics, an Overview," *Artificial Limbs* 11, no. 2 (1967): 5-21, 6.

...What we have said about the leg should apply with even more force to the arm, where the figure of the manikin familiar to all readers of books of neurology shows that the sensory loss in an amputation of the thumb alone is considerably greater than the sensory loss even in a hip-joint amputation.<sup>46</sup>

Although not everyone was clear what cybernetics meant or that it had a single meaning,<sup>47</sup> the concept of the human cybernetic system fit well with the more general idea that science would show the way of progress in powered upper-limb technology development, clinical and field studies, and commercial production. The concept inspired researchers in the field, and not just by designers of the Boston Arm in the 1960s and the Utah Arm in the 1970s.<sup>48</sup>

Although the arm in **Figure 1** appears to be a male arm, consistent with representations of users of non-powered upper-limb prosthetic devices, the focus of human cybernetic research was on mind-control of the body. The ideal users of these powered devices, according to engineering researchers, prosthetists, and occupational therapists of the period, were not adults males, but children because of their capacity to become "natural" users of the powered devices, akin to becoming proficient speakers of other languages.<sup>50</sup> The authors of the above image wrote in their 1967 article about these ideal users: "Here, age and motivation are important; for example, "thalidomide children" show tremendous learning capacity with complex prostheses, while many geriatric lower-extremity amputees are not able, or are not motivated, to use an artificial leg."<sup>51</sup>

## Canada

Themes in Canada's approach to prosthetics services were present from World War I, including the significant role of the federal government in product and service delivery, collaboration among Canadian institutions, and coordination of services among regions. Based on recommendations by a federal government commission headed by

Dr. Clarence L. Starr, the chief physician at the Hospital for Sick Children in Toronto, and future professor of surgery at the University of Toronto, the Department of Veterans Affairs operated all parts of the system through Sunnybrook Hospital in Toronto. This included manufacture, supply, fitting, and servicing of prosthetic devices for veterans free-of-charge. In keeping with prosthetic manufacturing practices in the US, Germany, and elsewhere following World War I, the development activities focused on the standardization of material and parts, and reduction of production costs. The central limb factory located in Toronto at Sunnybrook Hospital served eleven other centres located in cities across Canada.

As in the US, concerns about re-establishment of veterans into civilian life were behind the financing of prosthetic programs. During the inter-war period concerns were expressed about the pension and unemployment insurance payments to veterans. As well, there was a perception that large numbers of veterans had failed to re-establish themselves in civilian life. A 1936 study of employed by the Veterans' Assistance Commission found that the great majority of disabled veterans were unskilled.<sup>52</sup> Canada also shared with the US the view that science and engineering would be applied to getting disabled veterans into productive work and family life. Writing about Canada's Department of Veterans Affairs in the 1940s, Walter Woods noted that prosthetic services of the department were designed "to provide scientific physical rehabilitation of the disabled veteran which is so essential to his establishment in a useful occupation."<sup>53</sup>

But there were differences in the how and when that mission of science-based rehabilitation was implemented in the US and Canada. Although Canada's National Research Council hosted the International Conference on Amputations and Artificial Limbs in Ottawa in 1944, and formed an Associate Committee on Artificial Limbs within the NRC to provide direction to research on artificial limbs, little happened in Canadian research until 1949. In that year a laboratory facility was opened at the Sunnybrook Hospital in Toronto, and the first research engineer was hired, Colin McLaurin.<sup>54</sup> James Foort, who would subsequently lead the Winnipeg Prosthetic Research and Training Unit (PRTU) in the early 1960s, described the laboratory facilities they had in 1951 as a "broom closet made available when the janitors moved to better quarters."<sup>55</sup> In contrast to the US fundamental-research program to develop a powered upper limb, the focus in Canada in the 1950s was on making existing body-powered and mechanical-hand prostheses more useful through the use of new plastics and materials, novel suction-socket fittings, and cosmetic gloves. The NRC provided direction on this applied research, advising on new materials and techniques, and performing testing at its laboratories.

Although there were differences in approaches to research agendas, strong linkages existed between the two countries. Canadians were influenced by conferences the CRPD hosted in 1961, 1963, and 1965, and its model of research, development, testing, and evaluation of new prosthetic devices.<sup>56</sup> Americans were influenced by Canadian designs of myoelectric controllers and associated training courses. As well, personnel crossed the border. Colin McLaurin, for instance, worked at Sunnybrook from 1949 to 1957, then moved to Northwestern University in Chicago to become the founding director of the Prosthetic Research Center at the Rehabilitation Institute of Chicago. There he collaborated in development of the "Michigan Feeder Arm," an electrically powered limb for children born without arms.<sup>57</sup> It was one of the first electric-powered arms in the US that was used in daily activities, and a precursor of other powered limbs that were to be developed around the world during the next two decades. In

this position he also developed relationships with the leaders of the US Artificial Limb Program, which became the influential CPRD.<sup>58</sup> In 1963 McLaurin returned to Toronto to direct the Ontario Centre for Crippled Children's Prosthetic Research and Training Unit (PRTU).

PRTUs were established in 1963 in Winnipeg, Toronto, Montreal, and Fredericton as part of a federal government response to the crisis that arose from the prescription sale of thalidomide from April 1, 1961 to March 2, 1962.<sup>59</sup> In 1962, the Department of National Health and Welfare convened an expert committee on the rehabilitation of congenital anomalies associated with thalidomide.<sup>60</sup> The committee reported in December 1962. The recommendations called for an aggressive approach to rehabilitation, including the development of prostheses for infants, novel in terms of its approach and the devices that would be used:

If the normal development pattern of the infant is to be met, these cases must be immediately referred to other specialists for the early provision of limb prostheses; probably as early as two months of age. The fitting of the such apparatus is only the beginning: training the child to use and live with his new limbs will demands years of of care and supervision through the resources of a rehabilitation centre. Social, vocational and psychiatric problems, in addition to recognized paediatric and orthopaedic disabilities, will arise and co-operation between the many specialties involved in the team will be essential.<sup>61</sup>

The department took action, providing \$200,000 annually (starting in 1963) for three research and training units at the Rehabilitation Institute of Montreal, the Ontario Crippled Children's Centre (OCCC) in Toronto, and the Rehabilitation Hospital in Winnipeg.<sup>62</sup> The units were chosen because they offered teaching hospitals associated with medical schools. As the authors of the 1962 *The Report of the Expert Committee of the Habilitation of Congenital Anomalies Associated with Thalidomide* wrote: "limb abnormalities...can usually be met by existing paediatric facilities, particularly within university centres."<sup>63</sup> It was here that the expert committee wanted the training courses to be located because of the already, "very close relationships between the prosthetist, the physiatrist, and the orthopaedic surgeon."<sup>64</sup>

The other major component of the research strategy, to directly involve electrical engineer researchers in the teaching hospitals, was implemented as an afterthought. The expert committee made no recommendations for involvement of electrical engineers among the list of critical professionals to be associated with these units.<sup>65</sup> This was surprising because the expert committee foresaw that "[t]he use of external power in artificial limbs is in its infancy, and will undoubtedly be required in the long-term management of severely involved phocomelic children."<sup>66</sup> The concept of getting engineers to work in hospitals was buried in the last appendix to the expert committee report, in a paper prepared by the Department of Veterans Affairs prosthetic service centre.<sup>67</sup> Although the paper focused on the prescription and fitting of prosthetic appliances, it noted that external power projects were new and development would be needed to design upper-limb prostheses, and the requirement for research to be, "performed by specialized people in research establishments...and that a method of coordination be established" for the research units. This resulted in the inclusion of a fourth PRTU, UNB's Bioengineering Institute.<sup>68</sup>

The origins of the Canadian powered upper-limb programs were similar to the American program for World War II veterans in that they both arose in response to a specific crisis and to address the perceived needs of a user group. But whereas the

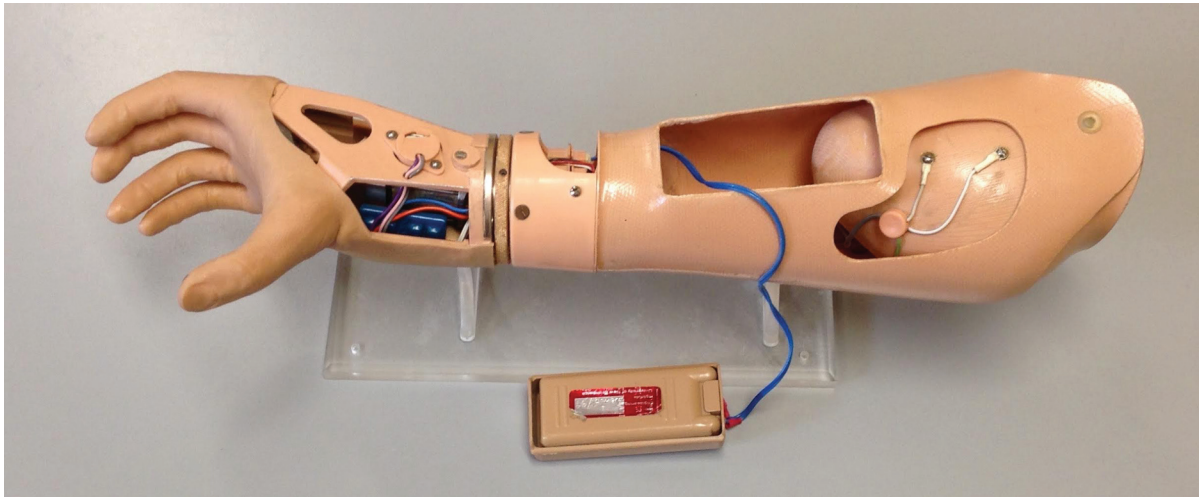
American response saw a lack of science in the field and a need to address this gap with fundamental studies, including involvement of industry in these studies, the Canadians saw the need for interdisciplinary teams at teaching hospitals in three regions that could do the work, and belatedly they brought electrical engineering researchers into the clinics. Although Canadian policy-makers saw powered upper limbs on the research horizon and fundamental research issues to resolve, no similar approach to the U.S. “crash” program to begin with fundamental studies emerged in response to the thalidomide crisis.

#### **North American Research and Development, 1945-1977<sup>69</sup>**

The “crash” fundamental research project begun in America in the mid-1940s resulted in a variety of projects to study and develop upper-limb power devices. These were undertaken in government, university, institute, and industrial facilities. One of the earliest US government funded projects to produce an electrically powered artificial arm occurred at New York University in the early 1950s. The research findings were that a myoelectric signal from muscle contractions varied in accordance with the size and location of the electrode as well as the type of contraction.<sup>70</sup> Evident of the early days of university-technology transfer, the researchers wrote in their paper that “[t]hese research findings were passed on to the Prosthetic Research Division of the International Business Machines Corporation for practical application.”<sup>71</sup> The passing of research findings, however, did not end in the commercialization of a device. More influential to the long term orientation of the field was research in the late 1950s at the University of California at Los Angeles that investigated whether electroencephalographic (EEG), electroneurographic (ENG), or myoelectric signals were the most promising for prosthetic device control. The authors favoured myoelectric control and outlined a number of concepts that would eventually be used in device designs.<sup>72</sup> It established the basic design concept for powered upper-limb devices that would guide North American R&D for the next half century.

During the period from the early 1960s to the late 1970s the design of major commercial products occurred at MIT, the University of Utah, UNB, and the Ontario Centre for Crippled Children. At MIT, electrical engineer Robert Mann began design on what would become the Boston Arm, inspired by Wiener’s cybernetic concepts. After substantial re-design by staff at Liberty Mutual following user trials in the 1970s, it became the first commercial myoelectrically-controlled elbow. At the University of Utah’s Center for Engineering Design, a student of Robert Mann, Steven Jacobsen, began work on the Utah Arm in the early 1970s. In Canada, UNB’s Institute for Biomedical Engineering began development of its three-state control system for powered limbs, which was to become the first North American control system in 1965.<sup>73</sup> And in the late 1960s, at the OCCC in Toronto, staff began work on the design of electronic elbows and hands for use by children. As with the Boston Arm, the design of the Utah Arm and devices at UNB and OCCC would all be strongly influenced by the movement of development into clinics and the involvement of users in the design process.

The line between experimental design and commercial product was fuzzy. Work to create products from these four initiatives was described by faculty and staff as biomedical-engineering design. It was experimental in that the newly designed or redesigned products were subject to testing in the laboratory and with patients in clinics, and in some cases publication of results and new design work. But the lack of uptake



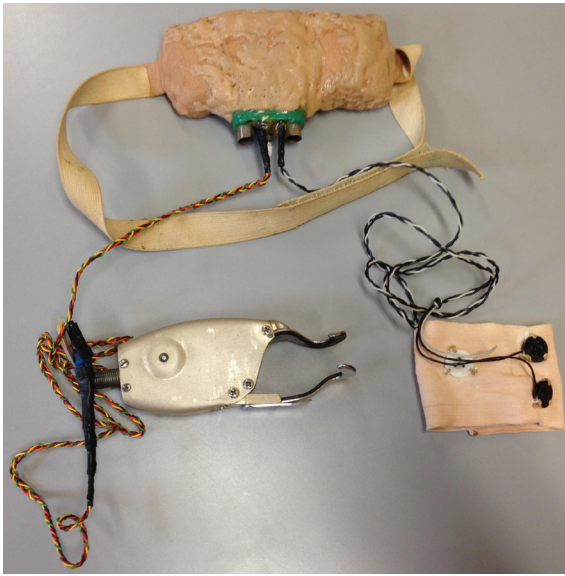
*Figure 2: VASI hand, circa 1970. Image copyright David Foord.*

by amputees and ever-changing designs, not to mention a likely lack of profitability on these designs, made the products something less than commercial products.

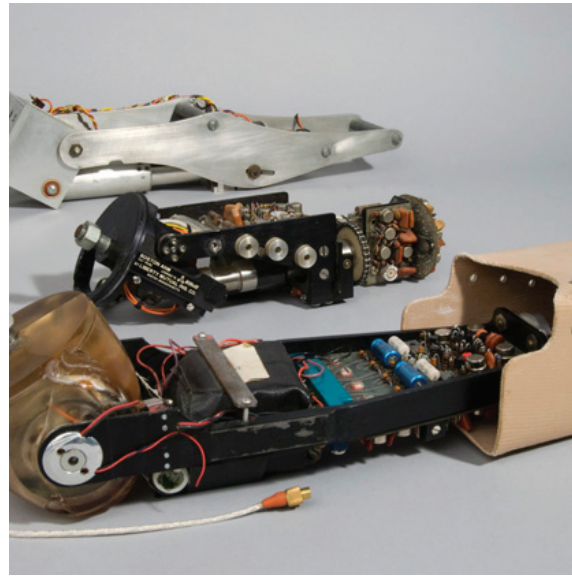
Although the commercial upper-limb myoelectric devices developed during the period shared many commonalities, the influence of local preoccupations can be seen in the artifacts in figures 2, 3 and 4. The circa-1965 UNB myoelectric-controlled upper limb in **Figure 3** and circa-1977 VASI myoelectric-controlled upper limb with UNB myoelectric control unit in **Figure 2** show the dramatic change from the purely functional “pliers on wires” approach to a naturalistic design, influenced by users in clinics who wanted prosthetic arms and hands that looked “natural” and, in turn, the policy prescription to locate engineering design activities in hospitals. This response to user feedback was addressed, in part, by re-designing the system to incorporate the batteries into the forearm, as illustrated in **Figure 3**.

The Boston Arm also evolved to incorporate user feedback as it moved from MIT faculty and student-led projects in the 1960s to product development work at Liberty Mutual in the early 1970s. However, notice the boxy design of the covering over the elbow area of the Boston Arm in the foreground of **Figure 4**, suggesting that the central preoccupation was with achievement of the engineering goals for functionality, not achievement of the naturalistic appearance.

The division between cybernetic and user-oriented approaches to the field can also be seen in the names of new journals founded in the 1960s and 1970s. The scholarly journal *IEEE Transactions on Systems, Man, and Cybernetics* was first published in 1960, although originally under the name *IRE Transactions on Human Factors in Electronics*. With the growth in cybernetic theory two spin-off journals were created in the 1960s. *IEEE Transactions on Systems Science and Cybernetics* was published from 1965 to 1970, and *IEEE Transactions on Man-Machine Systems* from 1968 to 1970. In 1971, the journals were combined under the name *IEEE Transactions on Systems, Man and Cybernetics* and focused on signal processing and analysis, and published monthly in three parts, with one dedicated to systems and humans, another to cybernetics, and a third to applications. At the other end of the spectrum was the International Society for Prosthetics and Orthotics’ *Journal of Prosthetics and Orthotics International*, introduced in 1977, with articles focused on clinically relevant practices, products, and services aimed at health-care professionals.



*Figure 3: VASI hand, circa 1960. Image copyright David Foord.*



*Figure 4: Boston Elbow Prototypes, 1966–1973. Image source MIT.<sup>74</sup>*

### Disestablishment in the United States

In 1977 the CPRD, the coordinating body of prosthetics R&D in the US, was dissolved by the National Academy of Sciences given concerns about the lack of science in its research program. Since its inception in 1959, the CPRD had coordinated funds from the federal agencies to direct the national research efforts in prosthetics. It held meetings on R&D progress and needs, evaluated products and techniques, published documents, reviewed research proposals, and promoted education. According to Childress, the “CPRD was action orientated. On the other hand the NRC was primarily an advisory group, and this difference in organizational function led to conflict between NRC and CPRD. In the mid 1970s, this conflict of operating styles resulted in CPRD losing its position within the NRC, which had been its “Alma Mater” for more than 30 years.”<sup>75</sup>

The demise of the CRPD was at least three years in planning. Ironically, CRPD insiders, including Clinton Compere and Colin McLaurin, called for the wind-down of the body in a 1973 review and report of the CPRD.<sup>76</sup> They suggested reorganization of the CPRD and CPOE and upgrading from committee status to a unified “Board on Rehabilitation Engineering for the Musculoskeletal and Sensory Systems.” The vision was for a body that would not only oversee steps between fundamental studies and device development, but also have broad responsibilities in evaluation, education, and service realms.<sup>77</sup>

This report was not acted upon. What was happening in the background was the transfer of the CPRD and CPOE from the National Academy of Sciences’ (NAS) Division of Engineering and Industrial Research to the newly created Assembly of Life Sciences. In early 1974, the Assembly of Life Sciences funded a project to review NAS activities in the field of prosthetics, orthotics, and sensory aid research, development, and education. The project was led by a visiting committee chaired by Dr. Melvin Glimcher, the Harriet M. Peabody professor of orthopaedic surgery at Harvard Medical School, and orthopaedic surgeon-in-chief at the Children’s Hospital Medical Center in Boston. He was also a long-time champion of the cybernetics approach to prosthetic-system

development and a strong critic of what he saw as the short-term apparatus focus of the engineering-oriented CPRD and CPOE.<sup>78</sup> The visiting committee members included three other professors of medicine and a professor of engineering and applied physics from Harvard University, as well as two NRC staff members. The visiting committee first met on June 28, 1974 in Washington, D.C., and the 222-page transcript of their meeting provides a fascinating glimpse into its operation and its members. Glimcher, the visiting committee chair, emerged as the strongest personality in the record.<sup>79</sup> At the meeting of the visiting committee on September 3-5, 1974, it was agreed that Glimcher would prepare an initial draft of the committee's final report.<sup>80</sup>

The report's main conclusions were that the "CPRD/CPOE can no longer continue to respond to the needs of the Federal agencies and the handicapped in a manner commensurate with the high standards of the NAS." Core problems identified by the visiting committee included that the CPRD and CPOE committees had not met in the past three years, had devolved responsibilities and authority to staff, prepared reports that were not first-rate, and directed peer reviews of grants and contracts for the Veterans Administration that were "woefully inadequate in terms of overall evaluation for scientific merit."<sup>81</sup> The recommendation was that the NAS-NRC "should undertake promptly a fundamental reorganization of its professional and administrative structure, and its organization, in the area concerned with the rehabilitation of the handicapped in order to be able to discharge its important responsibilities to the nation in a manner consistent with the highest professional standards."<sup>82</sup> According to the visiting committee, the field of rehabilitation research had expanded beyond prosthetics and orthotics and the CPRD had failed to "broaden the accumulation of knowledge in this particular field, and to hasten its useful application to the handicapped population."<sup>83</sup> Among its strongest criticism of the CPRD was that "[i]nstead of viewing their charge as one which involves a broad scope of basic and applied biomedical research, in addition to innovative development and sound engineering, so as to encourage truly signal advances, their attention remains fixed essentially as it has been in the past: an inordinate emphasis upon the relatively short-term development of immediately useful apparatus."<sup>84</sup>

The report was restricted in its distribution, and was limited to 50 copies.<sup>85</sup> Nevertheless, word leaked out about the visiting committee's conclusions and recommendations. Criticism of the report and the study came from CRPD staff, Douglas Hobson, then technical director of the University of Tennessee's Crippled Children's Hospital School, R. N. Scott of UNB, and many others. Dr. Colin McLaurin, chair of the CPRD, and A. Bennet Wilson, Jr. executive director of the CPRD, resigned their positions, as did a number of CRPD staff.<sup>86</sup> It was all to no avail. Even a letter from the director of the Veterans Administration Research Center for Prosthetics, a major funder of CRPD/CPOE activities, to the president of the National Academy of Engineering, did not result in preventing the anticipated termination of the two committees. The letter suggested that the CPRD/CPOE would be better located in an assembly or commission of the NAS other than life sciences, as past history had shown successful operation of the CPRD/CPOE in the former division of Engineering and Industrial Research. At the January 17-18, 1977 meeting of the executive committee of the Assembly of Life Sciences, the development of a new, more broadly focused rehabilitation committee was approved, sealing the fate of the CPRD/CPOE.

Underlying the plan for wind-down of the two committees was an alternative vision of science and technology in biomedical science, emphasizing a much greater role for

fundamental research. The vision was expressed in a report published by the NAS titled *Science and Technology in the Service of the Physically Handicapped*.<sup>87</sup> It was authored by a committee of the NAS's Division of Medical Sciences, Assembly of Life Sciences, and chaired by Walter Rosenblith, provost of MIT. Two of the eleven co-authors included Stephen Jacobsen from the University of Utah and his former professor, Robert Mann from MIT, lead designers of, respectively, the Utah Arm and the Boston Arm. With respect to powered upper-limb prostheses, the focus was on the separation of fundamental and applied research, and the role of cybernetics.<sup>88</sup> The report argued that:

The business of science is the search for new knowledge. A useful partition of research is into basic or fundamental research versus applied or goal-oriented research. Both are vital in the advance against handicapping conditions. Basic research tends to follow disciplinary lines, leading the investigator wherever the theory or data take him. Although nonspecific to handicapping conditions, basic neurophysiological research into the central nervous system, for example, leads to sensory input and motor control information central to cybernetic limb prostheses and sensory orthoses.<sup>89</sup>

Later in the same section the authors wrote of applied research:

The boundary between basic and applied research, however, is almost always somewhat blurred. In contrast to the search for new knowledge, applied medical research identifies a specific need in a target population and designs a device or therapy to satisfy that need. But, for example, research in prosthetics does not necessarily begin that way. Instead it may begin in relation to theoretical aspects of cybernetics, just as much biomedical research relates to fundamental knowledge in biochemistry. For example, research on multiple-degree-of-freedom, power-driven, upper- and lower-limb prostheses with force and position feedback using electromyographical signals on the man machine interface should be classified as basic research, at least for the present.<sup>90</sup>

This was more than a mere acknowledgement of the porous boundaries of the concepts. It was part of an attempt to reposition research and policy in powered upper-limb systems, from an orientation of engineering design of devices for users to a basic research field that examined theoretical concepts of cybernetics and the man-machine interface through the design, procurement, construction, and testing of devices. But as with the attempt to save the CPRD and CPOE, it was unsuccessful.

A week after the report was issued, on January 24, 1977, the CPRD and CPOE were finally disestablished.<sup>91</sup> It was the end of an era in the field of upper-limb myoelectric prosthesis R&D.

### Termination of PRTUs in Canada

In Canada, the process to terminate support in 1975 for the PRTUs was more straightforward. The plan in 1963 had been to terminate funding in 1972, although it was extended for a few years. Behind the scenes there were discussions of the federal government strategy to prosthetic services given the planned wind-up of the four PRTUs. Originally created in 1916 by the Department of Veterans Affairs, responsibility for prosthetic services was subsequently handed over to the Department of National Health and Welfare. The issue before the Department of National Health and Welfare was how to restructure the national strategy in light of the coming wind-ups of the PRTUs.

By the early 1970s it was becoming clear to the Department of National Health and Welfare that its PRTUs had not able to meet its goal of providing useful devices for victims of the thalidomide tragedy. This was not for lack of trying or development of useful devices for upper-limb amputees. Many of the children effected by thalidomide



had residual upper limbs and fingers with sensation, and often the digits were functional. What became clear to developers was that covering these up with an artificial limb with no sensory input was unattractive to potential users.

To help the Department of National Health and Welfare develop its strategy for prosthetic services, the federal government commissioned an independent report in 1973 from the chairman of the University of Ottawa's school of medicine sub-department of rehabilitation. Entitled "Prosthetic Services Study,"<sup>92</sup> it concluded there were three solitudes: (i) the prosthetic services of the federal government, (ii) the commercial sector, and (iii) universities and hospitals. It found that "in most instances, Prosthetic Services [of the federal government] seem to be weak in the areas of prescribing, manufacturing, fitting and servicing upper extremity amputees; the Commercial Sector is often found to be weak in servicing and maintaining, etc."<sup>93</sup> It concluded: "If consolidation of resources seems logical in some regions, a "national" approach seems desirable to Research and, furthermore, to meet the needs of those patients few in numbers who present complex problems."<sup>94</sup>

The response from the federal civil service was highly critical of the report and argued for a large role for the federal government. Dr. J. D. Copping, a medical doctor with the Department of Health and Welfare, found the study "biased from the beginning."<sup>95</sup> The 1973 report he authored on behalf of the government's prosthetics services division called for a large role for the federal government's prosthetic services group, and raised questions about the university and clinical-research groups.<sup>96</sup> The problems Copping saw was with the supply side: "The volume of devices emerging from the several research units in Canada was grossly exaggerated at the time the [federal prosthetic services engineering, testing and training] Unit was set up, and after a year or two of operation, found itself in a position of having no new devices worthy of putting into production. They then undertook a programme of finding other researchers, testing commercially available products, doing some research work on their own and involving themselves in some special fitting cases in the Toronto area."<sup>97</sup> The emphasis was on continued operation of the federal government's prosthetics services division to conduct research, develop, and evaluate prosthetic and orthotic devices and techniques, and pilot, manufacture, and test designs from research groups in Canada.<sup>98</sup> An expanded role for the federal government would, according to the report, "bridge a gap between the researchers in the prosthetic and orthotic field—who determine the need for the special devices and components, design them to suit the need, build and test prototypes—and suppliers ... Their function ends when the product is in such a condition that commercial production can be arranged by any manufacturer."<sup>99</sup> It concluded there was a large role for the federal agency in the treatment of patients and development of appliance "on a scale for which no single private or institutionally-based facility could muster sufficient human or financial resources."<sup>100</sup> By 1977, it was resolved that prosthetist training and other responsibilities would be transferred from the department's centre at the Sunnybrook Hospital in Toronto to provincially run hospitals, and production, engineering, testing, and training would be handed over to the National Research Council.

## Conclusion

The consensus view is that the design of US upper-limb prosthetics R&D programs after World War II was based on the assumption that the field was in a dark-age and needed fundamental scientific research to open a path for subsequent development

and design of modern prosthetic devices. Childress, Hobson, Gailey, Serlin, and others emphasize the divide of pre- and post-war periods, not the continuity, and that the divide was cleaved by US federal government funding programs to undertake fundamental research. Less consensus exists on the reason for wind-down of these programs by the mid-to-late 1970s. We argue the reason for end of the CPRD, CPOE, and the associated funding programs was because it was judged by the NAS-NRC to be deficient in the performance of biomedical research, including a failure to keep abreast of the expanding field of rehabilitation, a woefully inadequate process for evaluation of scientific merit of grants and contracts, and an inordinate emphasis upon short-term design of devices.<sup>101</sup>

These judgements were framed within the concepts of fundamental and applied research, and a distinction between a basic-research field oriented to investigation of cybernetic theories, and another directed to device development. According the NAS-NRC, the lack of attention by the CPRD to fundamental research practices and advances meant it was also unable also meet its broad duty to useful application and innovative development for disability communities. In the context of the forces identified by Harrison and Hoberg in Canada-US regulatory affairs, the National Academy of Sciences emerged as the major policy entrepreneur behind the wind-up of the research funding for the field, acting on the deeply held belief in new frontiers of cybernetics and that science offered the best means to explore these unknown territories.

In contrast, the Canadian federal government's response to veteran-amputees was to hire an engineer and establish a workshop to apply new materials to prosthetic devices. In 1963 when the PRTU funding program was founded, the policy discussions focused on the importance of the location of work and clinic-based interdisciplinary relationships between the prosthetist, physiatrist, orthopaedic surgeon, and later the engineer. There was also an emphasis on creation of centres of expertise within regions, foreshadowing a preoccupation of Canadian science and technology policy with creation of interdisciplinary research networks of centres of excellence. Upon wind-down the policy focused again on relationships. But consistent with Canadian federal research policy of the period, the central theme that emerged concerned the need for a strong role for a federal institution to mediate the Canadian solitudes among hospitals, universities, industry, and the federal government.<sup>102</sup>

The contemporary preoccupation in Canada with ideas of these solitudes, and the role of the federal government to bridge these divides as well as regional interests, recalls the view of MacLeod and Jarrell about persisting choices inherited from the colonial past and the enduring influence on the politics of science.<sup>103</sup>

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## Endnotes

- 1 Thanks to Gregory Kealey, R. Steven Turner, David Pantalony, and William Knight for reviewing and offering helpful comments to improve this article.
- 2 Roy M. MacLeod and Richard A. Jarrell, "Introduction," *Scientia Canadensis* 17, (1993): 1-2, 1.
- 3 See David Foord and Peter Kyberd, "From Design to Research: Upper Limb Prosthetic Research and Development in Canada, 1960-2000," *Scientia Canadensis* 38, 1 (2015): 50-71.
- 4 Nelly Oudshoorn and Trevor Pinch, "User-Technology Relationship: Some Recent Developments," in *Handbook of Science and Technology Studies* 3d ed., ed. Edward Hackett (Cambridge: Massachusetts Institute of Technology, 2008) 542; E. von Hippel, "The Dominant Role of Users in the Scientific Instrument Innovation Process," *Research Policy* 5, 3 (1976): 212-239.
- 5 Thomas Misa, *Leonardo to the Internet: Technology & Culture from the Renaissance to the Present* 2nd ed., (Baltimore: Johns Hopkins University Press, 2011).
- 6 Colin J. Bennett, "What is policy convergence and what causes it?" *British Journal of Political Science* 21, 2 (1991): 215-233; Christoph Knill, "Introduction: Cross-national policy convergence: concepts, approaches and explanatory factors," *Journal of European Public Policy* 12, 5 (2005): 764-774.
- 7 Seymour Martin Lipset, *Continental Divide: The Values and Institutions of the United States and Canada* (New York: Routledge, 1990); Lispett argues that from the differences in revolutionary and counter-revolutionary origins, the US derived a political culture characterized by antistatism, individualism, populism, and egalitarianism, in contrast to Canada's more class-conscious, elitist, law-abiding, statist, collectivity-oriented, and particularistic culture. Michael L. Skolnik, "Lipset's 'Continental Divide' and the Ideological Basis for Differences in Higher Education between Canada and United States," *Canadian Journal of Higher Education* 20, 2 (1990): 81-93; On page 87 he states that "Perhaps the most striking differences in higher education between the two nations are along the public-private axis.;" Kathryn Harrison, *Risk, Science and Politics: Regulating Toxic Substances in Canada and the United States* (Quebec City: McGill-Queen's University Press, 1994) 8-9; On the growing comparative policy literature that suggests that there are different "national styles of regulation." Harrison states: "The U.S. style has been characterized as open, adversarial, formal, and legalistic." She found the Canadian policy seems to fit within an alternative pattern, associated with European and Japanese policy making, and that "has been described as closed, informal, and cooperative."
- 8 Kathryn Harrison, "Between science and politics: Assessing the risks of dioxins in Canada and the United States," *Policy Sciences* 24, 4 (1991): 367-388; Kathryn Harrison, "Ideas and environmental standard setting: a comparative study of regulation of the pulp and paper industry," *Governance* 15, 1 (2002): 65-96; Kathryn Harrison, "Is cooperation the answer? Canadian environmental enforcement in comparative context," *Journal of Policy Analysis and Management* 14, 2 (1995): 221-244; George Hoberg Jr., "Risk, Science and Politics: Alachlor Regulation in Canada and the United States," *Canadian Journal of Political Science* (1990): 257-277; Michael Howlett, "The Judicialization of Canadian Environmental Policy, 1980-1990: A Test of the Canada-United States Convergence Thesis," *Canadian Journal of Political Science* 27, 1 (1994): 99-127; Gabriela Pechlaner and Murray B. Rutherford, "Common Future, Different Policy Paths? Managing the Escape of Farmed Atlantic Salmon in British Columbia and Washington State," *BC Studies* 150 (2006): 43.
- 9 Eric Montpetit, "A policy network explanation of biotechnology policy differences between the United States and Canada," *Journal of Public Policy* 25, 3 (2005): 339-366; in this paper networks explain why Canada has a more restrictive biotechnology policy than the United States.
- 10 *Ibid.*, 5.
- 11 Pholecomic limbs have been connected to the use of thalidomide.
- 12 *Ibid.*, 2.
- 13 George Hoberg, "Sleeping with an elephant: the American influence on Canadian environmental regulation," *Journal of Public Policy* 11, 1 (1991): 107-131.
- 14 The Department of Veterans Affairs' prosthetic limb factory was located at Sunnybrook Hospital in Toronto, which distributed materials and components to 11 service centres across the country.
- 15 President Abraham Lincoln signed the charter of the Academy of Sciences when it was set up during the Civil War. That charter required that the academy act as adviser to the government in scientific matters, although it is not a government agency. The National Research Council was established by the academy in 1916 at the request of President Wilson, to enable scientists generally to associate their effort with that of the limited membership of the academy.

- 16 Walter Woods, *Rehabilitation (A Combined Operation): Being a History of the Development and Carrying Out of a Plan for the Re-establishment of a million young veterans of World War II by the Department of Veterans Affairs and its predecessor the Department of Pensions and National Health* (Ottawa: Edmond Clothier, 1953) 348.
- 17 D.S. Childress and M.V. Podlusk, "Myoelectric control – Letter to the editor," *Medical & Biological Engineering* 7, 3 (1969): 345.
- 18 Ibid.
- 19 Louise Boldon, "A History of Myoelectric Control" (Master's Thesis, University of New Brunswick, 1983).
- 20 B. Popov, "The Bio-Electrically Controlled Prosthesis," *Journal of Bone & Joint Surgery* 47B (1965): 3.
- 21 Ibid.
- 22 Ibid.
- 23 Dudley S. Childress, "Development of rehabilitation engineering over the years: As I see it," *Journal of Rehabilitation Research and Development* 39, 6 (2002): 6.
- 24 Ibid.
- 25 Robert Gailey, "As history repeats itself, unexpected developments move us forward," *Journal of Rehabilitation Research and Development* 44, 4 (2007): xii.
- 26 A. Bennet Wilson, "History of Amputation Surgery and Prosthetics," *Atlas of Limb Prosthetics: Surgical, Prosthetic, and Rehabilitation Principles* ed. John H. Bowker and John W. Michael (Saint Louis: Mosby-Year Book, 1992) accessed July 31, 2009, <http://www.oandplibrary.org/alp/chap01-01.asp>.
- 27 Ibid.
- 28 Douglas Hobson, "Reflections on rehabilitation engineering history: Are there lessons to be learned," *Journal of Rehabilitation Research and Development* 39, 6 (2002): 17-22.
- 29 Ibid.
- 30 Thalidomide is a sedative that was prescribed in the 1960s to pregnant women for nausea. It caused severe congenital limb deficiencies in children. Governments in Canada and Western Europe, where the problem was most acute, established research centers to develop prostheses for these children. The Vietnam war resulted in another dramatic increase in the number of US servicemen returning home with amputations and spinal cord injuries.
- 31 Ibid, 17.
- 32 David Serlin, "Engineering Masculinity: Veterans and Prosthetics after World War Two," in *Artificial Parts, Practical Lives: Modern Histories of Prosthetics*, ed. Katherine Ott, David Serlin, and Stephen Mihm (New York: New York University Press, 2002); David Serlin, "The Other Arms Race," in *Replaceable You: Engineering the Body in Postwar America* (Chicago: The University of Chicago Press, 2004).
- 33 Ibid., 47.
- 34 Ibid., 54.
- 35 Ibid., 55.
- 36 Ibid., 56.
- 37 Ibid.
- 38 For an excellent history of rehabilitation in the US read Beth Linker's *War's Waste: Rehabilitation in World War I America* (Chicago: The University of Chicago Press, 2011). It examines the change from the pension system that persisted through the nineteenth century to the institution of rehabilitation programs during World War I. The goal of reducing cash payments to veterans meant efforts to cure veterans of their disabilities so they could make a speedy return to work. She argues rehabilitation was a process of making a man manly, and restoring social order by remaking men into producers of capital.
- 39 US Department of Health, Education and Welfare, Office of Vocational Rehabilitation, *Progress in Prosthetics* (Washington: US Government Printing Office, 1962) 2.
- 40 Samuel W. Alderson, "The electric arm," *Human Limbs and Their Substitutes* (1954): 359-408.
- 41 US Department of Health, *Progress*, 2.
- 42 Ibid., 21.

- 43 Norbert Wiener, *Cybernetics: the science of control and communication in the animal and the machine* (Cambridge: MIT Press, 1948).
- 44 Flo Conway and Jim Siegelman, *Dark Hero of the Information Age: In Search of Norbert Wiener, The Father of Cybernetics* (New York: Basic Books, 2005).
- 45 Ibid.
- 46 Ibid., 24-25.
- 47 Ibid. Michael Marcus in a review of *Dark Knight* wrote that not only was it not clear to him what cybernetics really is, but whether it is even a science. Ronald Kline in “Where are the Cyborgs in Cybernetics?” stated that “The wide- spread interest in cybernetics led to multiple meanings of the term.” *Social Studies of Science* 39, 3 (2009): 331–362, 352.
- 48 Ronald Kline states in “Where are the Cyborgs in Cybernetics?” that this was one of only four fields which featured cyborgs in cybernetics because the chief texts of cybernetics were mainly concerned with analogies between humans and machines, not the fusion of humans and machines, which was the realm of cyborgs. Italics used as per the original article. See pages 336 and 351.
- 49 Ames B. Reswick and Lojze Vodovnik, “External Power in Prosthetics and Orthotics, an Overview,” *Artificial Limbs* 11, 2 (1967): 5-21, 6.
- 50 Ibid., 17.
- 51 Ibid., 6. The U.S. FDA did not approve thalidomide for marketing and distribution in US. It was, however, distributed in the US in by Richardson-Meril and in “clinical trials,” Seventeen infants in the US were reported to have Phocomelia syndrome as a result of thalidomide. Development of artificial limbs of these children did not emerge as a public policy preoccupation in the US. See: George J. Annas and Sherman Elias, “Thalidomide and the Titanic: reconstructing the technology tragedies of the twentieth century,” *American Journal of Public Health* 89, 1 (1999): 98-101, 99.
- 52 Although unemployment rates of veterans dropped in 1939 with mobilization of troops overseas and expansion of the war economy.
- 53 Woods, *Rehabilitation* 348.
- 54 Trained as an aeronautical engineer, he would later become the the first director of the Ontario Centre for Crippled Children’s Prosthetic Research and Training Unit (PRTU). He is credited by Dudley Childress as being one of the founding fathers of the field of rehabilitation engineering, and is “perhaps the most prolific, practical, and broad-based designer/innovator the field has ever known.” D. Childress, “A tribute to Colin A McLaurin 1922-1997: Build, don’t talk,” *Journal of Rehabilitation Research and Development* 35, 1 (1998): vii.
- 55 Ibid.
- 56 R.N. Scott, author interview, May 5, 2010.
- 57 Ibid. It was developed in collaboration with a Michigan medical doctor, Dr. George Aitken,
- 58 Ibid.
- 59 By September 1964 the Department had identified 82 children affected by thalidomide, with most in Ontario and Quebec.
- 60 Among the ten clinical experts on the committee were Dr. John Hall from the Ontario Crippled Children’s Center and Dr. Gustav Gingras from the Rehabilitation Institute of Montreal. *The Report of the Expert Committee of the Habilitation of Congenital Anomalies Associated with Thalidomide*, dated December 1962, was obtained under an access to information request. These and other primary documents from the Department of National Health and Welfare are located at Library and Archives Canada in Ottawa, Canada.
- 61 Ibid., 2.
- 62 The OCCC was located on the other side of the brook from Sunnybrook Hospital. The grant was continued until March 31, 1975, three years after the termination date of March 31, 1972.
- 63 Department of National Health and Welfare, *The Report of the Expert Committee of the Habilitation of Congenital Anomalies Associated with Thalidomide*, (Ottawa: 1962) 1.
- 64 The view about location of centres at research hospitals proved useful, although not because of relationships among prosthetists, physiatrists, and orthopaedic surgeons. In the case of the OCCC, the key clinic-based relationships were between the users, occupational therapists, research design engineers, product design engineers, prosthetists and product managers.

- 65 Ibid., 5.
- 66 Ibid. The assumption that externally powered artificial limbs would be desired by users and more useful than phocomelic limbs turned out to be wrong in many cases. This was an assumption made not only by policy makers but also by the aforementioned research design engineers.
- 67 R.E. Gilpin, Department of Veterans Affairs, Canada Prosthetic Services Centre, *The Prosthetic Treatment of Children with Congenital Deformities of the Extremities, Report No. 28* (Ottawa: Government of Canada, 1962).
- 68 Ibid., 34.
- 69 See footnote 2 for references to our recent paper in this journal on the history of development and commercial myoelectric upper-limb prostheses in Canada and the US.
- 70 W. Berger and C.R. Huppert, “The use of electrical and mechanical muscular forces for the control of an electrical prosthesis,” *American Journal of Occupational Therapy* 6, no. 3 (1952): 110-114.
- 71 Ibid.
- 72 G. Weltman, H. Groth and J. Lyman, *An Analysis of Bioelectrical Prosthesis Control. Report No. 59-49*, (Los Angeles: Department of Engineering, University of California, 1959).
- 73 In three-state systems a chosen muscle was trained to produce a strong EMG signal to do one function (e.g. open the hand), and a moderate signal to do another function, close the hand. In other words, one muscle controlled two functions. In North America, UNB pioneered the three-state system, first designing and manufacturing systems for use in experimental fittings at the Ontario Crippled Children’s Centre. In Europe Professor Hannes Schmidl at INAIL in Italy developed and used a similar circuitry in a three state controller. See: Bill Sauder, “Application of a Three-State Myoelectric Control System,” *Journal of the Association of Children’s Prosthetic Orthotic Clinics* 16, no. 1 (1977): 9-12.
- 74 Image access October 12, 2016, <http://museum.mit.edu/150/10>.
- 75 Childress, “As I see it,” 7.
- 76 *Report of Ad Hoc Committee to Review Activities of the Committee on Prosthetics Review and Development and the Committee on Prosthetic/Orthotic Education, Division of Medical Sciences, National Academy of Sciences* (Washington, D.C.: National Research Council, March 1973). National Academies of Sciences documents were accessed at the NAS archival records office in Washington, D.C.
- 77 Ibid., 2.
- 78 Glimcher’s enthusiasm for cybernetics dated from his years as a Harvard medical student and attendance of a Wiener lecture in the 1940s. The enthusiasm persisted as he rose to positions as an associate professor of orthopaedic surgery at Harvard, director of the orthopaedic research laboratories at Massachusetts General Hospital, and associate of Liberty Mutual Insurance. The interest lead him in 1961 to visit the joint Machine Research Institute/Central Research Institute in Moscow in 1961 to view a demonstration of the myoelectric-controlled Russian Hand. And then, a year later, Glimcher had his fateful meeting with Wiener at the Massachusetts General Hospital while Wiener was recovering from a broken hip. Wiener shared his speculations that servomechanisms could be used to link the brain to an artificial limb. Melvin Glimcher was intrigued and recruited MIT mechanical engineering professors to investigate the design of mind-controlled artificial arms.
- 79 *Transcript of Proceedings, National Research Council, Meeting of the Visiting Committee for Committee on Prosthetics Research and Development and the Committee on Prosthetic-Orthotic Research, June 28, 1974, Washington, D.C.* (Falls Church, Virginia: Bowers Reporting Company, 1974).
- 80 Memorandum from T. Vogl to T.F. Rogers dated September 26, 1974, regarding “Meeting between Dr. Melvin J. Glimcher and T.F. Rogers in Boston, Massachusetts, on September 19, 1974.”
- 81 *Visiting Committee, Transcript*, 1-2.
- 82 Ibid., 4.
- 83 Ibid., 23. *The Rehabilitation Act of 1973 (HR 8070)*, an attachment to the report, would have provided information for the visiting committee members on this expansion of the rehabilitation field.
- 84 Ibid.
- 85 In a document dated November 13, 1974 from Dr. Thomas Kennedy, Jr. to Dr. Thomas Vogl, Kennedy wrote: “I spoke with Dr. Glimcher on November 12, 1974 and among other subjects we discussed the distribution of the Final Report. His feeling was that its distribution should be restricted as much as possible and to that end

- he believes that it is not necessary to give copies to the CPRD Committee or its Chairman since their terms have expired anyhow. He also feels that is not necessary to give copies to all CPRD staff.”
- 86 Memorandum from CRPD staff dated February 20, 1975 to Dr. Phillip Handler, President of the NAS; Letter from Douglas Hobson to Philip Handler dated August 21, 1975; and Letter from R. N. Scott to Philip Handler dated March 17, 1975.
- 87 National Academy of Sciences, Science and Technology.
- 88 *Committee on National Needs for the Rehabilitation of the Physically Handicapped, Division of Medical Sciences, Assembly of Life Sciences, National Research Council and National Academy of Sciences, Science and Technology in the Service of the Physically Handicapped*, (National Academy of Sciences: Washington, 1976).
- 89 Ibid., 26.
- 90 Ibid., 27.
- 91 Memorandum from Dr. S.D. Cornell, Executive Director of the Assembly of Life Sciences, National Research Council to Councilman Morgan, M.D., dated January 27, 1977.
- 92 Bernard Talbot, *Prosthetic Services Study, No 228*, unpublished report for the Government of Canada.
- 93 Ibid., 17.
- 94 Ibid., 19.
- 95 Memorandum from Dr. J.D. Copping to M14, dated January 11, 1974.
- 96 J.D. Copping, *Prosthetics Services Management Review and Other Related Material*, unpublished report of the Department of Health and Welfare, Ottawa, 1973.
- 97 Ibid., 13 and 14.
- 98 Ibid., 9.
- 99 Ibid., 13.
- 100 Ibid., 15.
- 101 Although this is the primary explanation for the policy change, there is also indirect influence of disability rights activists in demanding governmental and social organizations address the physical and social barriers faced by the disability community. This included the lobbying of Congress to pass the 1973 Rehabilitation Act, which influenced the visiting committee’s view of the expansion of the rehabilitation field beyond prosthetics and orthotics.
- 102 G. Brent Clowater, “Canadian Science Policy and the Retreat from Transformative Politics: The Final Years of the Science Council of Canada, 1985-1992,” *Scientia Canadensis* 35, 1-2 (2012): 107-134, 107.
- 103 MacLeod and Jarrell, “Introduction,” 1.