

# **Upper Limb Prostheses**

## **A Review of the Literature**

### **With a Focus on Myoelectric Hands**

By

**WorkSafeBC Evidence-Based Practice Group**

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## About this report

### Upper Limb Prostheses – A Review of the Literature With a Focus on Myoelectric Hands

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#### About the Evidence-Based Practice Group

The Evidence-Based Practice Group was established to address the many medical and policy issues that WorkSafeBC officers deal with on a regular basis. Members apply established techniques of critical appraisal and evidence-based review of topics solicited from both WorkSafeBC staff and other interested parties such as surgeons, medical specialists, and rehabilitation providers.

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## Executive summary

Myoelectric prostheses of the upper limb increase range of motion and improve overall function of the upper limb for people with missing hands. These prostheses function via surface electrodes which are placed in the socket to detect and amplify muscle action of the residual limb. A terminal device, which is either a hand or a hook, is operated by a small electric motor and sometimes accompanied by a microprocessor.

To compile the groundwork that will help develop an appropriate coverage policy on myoelectric prostheses at WorkSafeBC, the Evidence-Based Practice Group undertook a review on their usage in acquired, below-elbow, upper limb deficiencies.

We searched the medical literature available through various search engines and libraries, such as PubMed, EMBASE, and the Cochrane Library. To gather more publications, we searched relevant institution/organization websites, including Health Canada, the US Department of Veterans Affairs, and the State of Washington Department of Labor and Industries. We included studies on ‘myoelectric hands’ without discriminating against any study designs. We excluded publications which reported solely on congenital limb deficiencies or on surgical aspects of upper limb amputations. Studies on prosthetic applications only for pediatric amputees were also excluded. Only publications in English were included. We reviewed 205 relevant abstracts and, after applying our evaluation criteria (Appendix 1), included 37 studies in this review.

Only one of these 37 studies was a systematic review<sup>1</sup> and is rated as providing level 2 evidence, based on the EBPG criteria. (Appendix 2) This systematic review focused on prosthesis rejection rates and related factors, as well as patterns of wear and consumer satisfaction. The remaining 36 studies were clinical studies, surveys, and case reports. Surveys included interviews with amputees and questionnaires sent via mail, or conducted via telephone or Internet. Some had clinical components (such as activities of daily living (ADL) tests, range of motion (ROM) tests, or technical check-ups of the prosthesis), some were before/after studies (comparing two different prostheses used by the same person), some analyzed amputee chart data retrospectively, and some were follow up (after myoelectric hand application) studies. Overall, the evidence level for these 36 studies ranged from 3 to 4. (Appendix 2)

Most of these studies (29 out of 37) included a questionnaire part (in person or via Internet or mail).<sup>1,2,4-26,161-163,165</sup> Except for 13 studies,<sup>1,2,8,14-17,26,28,161-163,165</sup> which had sample sizes over 100, the rest contained relatively small sample sizes. Sixteen of the studies reported that the type of prosthesis was a significant factor related with usage/acceptance.<sup>1,7-9,12,14,16,17,22,25,26,28,29,161,162,165</sup> According to 10 studies, time between

amputation and prosthetic fitting was another factor affecting prosthetic usage and acceptance,<sup>1,6,7,12,20,25,31,88,165,167</sup> however, 5 studies disagreed with this conclusion.<sup>18,22-24,26</sup> Training on prosthetic use and availability/continuity of rehabilitation services were other controversial factors for prosthetic acceptance. Some studies agreed<sup>1,4,5,9,10,17,21,25,161,165</sup> and others disagreed or were inconclusive<sup>20,22,167</sup> that these were factors affecting acceptance. According to some studies, range of motion (ROM) was better with myoelectric prostheses compared to ROM with a conventional body-powered prosthesis.<sup>8,23,25</sup> In general, there was agreement that myoelectric prostheses offered better cosmetic appearance but were more costly in terms of initial fitting and maintenance.<sup>5,8,17,32,87</sup>

The overall conclusion from this review is that prosthetic choice should be decided on an individual basis and needs a thorough evaluation and follow up of the amputee by a multidisciplinary team.<sup>4,5,10,17,30,32,33,37,54</sup> Research to date supports that the myoelectric prosthesis has become one of the standard prosthetic options and might be a cost effective choice when used for the appropriate patient.<sup>10,23,33</sup> Prosthetic use may increase the functional capacity of a person with a missing hand and could shorten the return-to-work process.<sup>4,5,11,15,17,20,26,32,46,88</sup>

Coverage policies on myoelectric prostheses vary across jurisdictions and institutions. This is partly due to the limited clinical evidence from a scarce number of studies on myoelectric prostheses. For more powerful and reliable research results, development of standard outcome measures and collaboration between research teams from different research centres is crucial. Myoelectric prostheses may well become more affordable if produced in larger quantities. However, the expensive device development process and small market of amputees will always remain as limitations. Therefore, coverage policies need to be based on patients' gains in functionality and quality of life, as well as on return to work and productivity variables, rather than being based solely on the initial and/or ongoing maintenance expenses of any particular prosthesis product.

## Introduction

In the United States, about 1.7 million people live with limb loss and approximately 185,000 amputation-related hospital discharges occur annually.<sup>34</sup> Although trauma-related amputations are decreasing compared to disease-related amputations (the annual incidence rate in the US of trauma-related amputations dropped from 11.37 to 5.86 between 1988 and 1996), they still constitute the majority of upper limb amputations.<sup>35</sup> Usually, young, active, and economically productive people are affected by traumatic amputations.<sup>36</sup> Upper limb traumatic amputations occur twice as frequently as traumatic amputations of lower limbs.<sup>35,37</sup> In 1984, major upper limb amputations (excluding thumb and fingers) made up 15% of all acquired major limb amputations in the United States. Acquired upper limb loss was more common in males between the ages of 15-45 and for 75% of these cases the cause was trauma.<sup>38</sup> Dillingham et al. studied nationally representative hospital discharge data from 1988-1996 in the United States. About 70% of all upper limb amputations were trauma-related and most were below the elbow.<sup>35</sup> In Denmark, upper limb amputations were 3% of all amputations and 74% were trauma-related, generally occurring in unskilled or skilled industrial jobs, and in traffic accidents.<sup>39</sup> In 1986, in the UK, upper limb amputees were about 17% of the total amputee population.<sup>4</sup> In New South Wales, Australia, major upper limb amputations accounted for 5-6 % of all major amputations in the period 1991-1994, and the rate of trauma-related amputations amongst all major upper limb amputations increased from 49% to 57%, from 1991 to 1993.<sup>30</sup> A descriptive study from England reported arm amputations due to accidents to be double the number compared to disease-related ones (in the 1958-1988 period), and the majority of them occurred in industrial accidents.<sup>40</sup> In a survey of Australian upper limb amputees, 31% of 70 respondents were transradial and 10% were through-wrist amputees.<sup>41</sup> In an urban area in Finland, in 1984-1985, the rate of major upper limb amputations, which required prosthetic application, was 0.3 per 100,000 persons per year.<sup>42</sup> Bhaskaranand et al. studied upper limb amputees fitted with prostheses in India. Sixty-six percent were below-elbow amputees.<sup>43</sup>

Upper limb amputation with hand loss is extremely devastating. The role of the hand in human life is not limited to physical/functional movements, but, rather, is intimately intertwined with psychosocial roles including gestures, caressing, communication, and sensation.<sup>7,37</sup> Thus, successful rehabilitation after upper limb amputation requires a multi-dimensional, interdisciplinary approach.<sup>15,33,44,45</sup> Selection of the appropriate prosthetic device that provides the best prehension and functional movement is an important goal of rehabilitation. The amputee's physical and cognitive capacity (e.g. amputation level, stump muscle capacity); functional, recreational and vocational needs, psychosocial acceptance, availability of resources (e.g. health care system, insurance coverage), accessible medical/technical support for prosthetic fitting and follow up (e.g. living in

rural or urban areas) influence the prosthetic choice.<sup>32,36</sup> For example, a study by LeBlanc comparing prosthetic use in different countries shows the effect of cultural and psychosocial factors along with functional needs on prosthetic choices. According to this study, 72% of upper limb prosthesis users in the US preferred hooks as a terminal device; whereas in three European countries this percentage was lower, varying between 12-30%.<sup>44</sup>

## Objective of this review

Rehabilitation of amputees with acquired limb loss as a result of workplace injuries is an important component of compensation policy and practice. At WorkSafeBC, the rehabilitation team works collectively to accomplish a timely and productive ‘return to work’ for workers with amputations. Prosthetic application is an essential part of the rehabilitation process and the ability to ‘return to work’ is enhanced when appropriate prosthetic devices are employed.<sup>4,20,30,46</sup> However, if the chosen prosthesis is inappropriate for the amputee’s functional, cosmetic and vocational needs, the probability that it will be kept, utilized and contribute to ‘return to work’ is significantly reduced. Prosthesis rejection rates in the literature vary between 8% and 50%.<sup>4,5,7,8,16,18,22,23,26,27,159</sup> There have been extraordinary developments in upper limb prosthetic technology – including myoelectric hands – in recent decades. Clinical and vocational rehabilitation teams of WorkSafeBC need up-to-date technological/clinical information to provide the most suitable prosthesis for the worker with an amputation. The Health Care Services department needs reliable cost-effectiveness information on upper limb prostheses, particularly on those which utilize the most expensive technology (i.e. myoelectric hands). Our objective of this review is to provide up-to-date information on upper limb prosthetic devices (specifically on myoelectric hands), their clinical applications, rejection/acceptance rates, and cost effectiveness. This review will support WorkSafeBC officers in making informed clinical and administrative decisions regarding prosthetic devices for workers with upper limb amputations.

## Background

### *Upper limb prostheses*

Upper limb prosthetic devices are either passive or active. Passive prostheses, with no moving parts, are generally used for cosmetic purposes. Active prostheses may be body-powered or externally-powered. Hybrids of these two systems are also available. A body-powered prosthesis usually employs a harness and cables. A variety of terminal devices (hooks, hands) can be attached. According to LeBlanc (1988), 28% of prehensors in use in the US were hands (both passive and active); whereas in the UK, West Germany and

Sweden the percentage of hand prehensors were 76%, 88%, and 70%, respectively.<sup>44</sup> The advantages of body-powered prostheses include: simple operational mechanisms with intrinsic skeletal movement (which voluntarily opens/closes a terminal device), silent action, light weight, moderate cost, durability and reliability, and rough sensory feedback about the positioning of the terminal device.<sup>30,33,38,47,48</sup> They are utilized more often in less-developed countries with scarce medical and rehabilitation infrastructure and technical resources. As Bhaskaranand points out, prosthetic rehabilitation of patients with financial constraints requires durable and low cost prostheses.<sup>43</sup> Body-powered prostheses are also preferred by amputees living in rural areas (far from prosthetic centres), as well as by workers who are in labour-intensive manual and outdoor occupations. In general, prostheses used at challenging work environments are at a higher risk of exposure to corrosive materials, water or heat.<sup>6,17,25,30,37,48,49</sup> Externally-powered prostheses can utilize electric, pneumatic or hybrid electrohydraulic power systems. However, because of engineering limitations of the other two, electric systems with battery power sources have become more common.<sup>47,50</sup> Signals that control the motion of the prosthetic device are captured and processed by myoelectric technology. Once merely experimental, myoelectric hand technology has improved significantly since clinical applications were first used in the 1960s and 1970s.<sup>51-53</sup>

### *Myoelectric prostheses*

Myoelectric technology uses electromyographic (EMG) activity, a form of electrical signal, from the voluntary movements of the stump muscles. EMG signals, which control the flow of energy from the battery to the electric motor, are captured through surface electrodes. The amplitude of the EMG signal is generally proportional to the contraction of the residual muscle. After amplification and transmission, the myoelectric control system activates the electric motor to operate the terminal device.<sup>30,33,51,54,55</sup> Surface electrodes can be affected by donning, or by surface conditions such as perspiration. As well, during the journey from the muscle to the skin's surface, EMG signals may encounter noise and interference from other tissues. One option to increase signal control is needle/implant electrodes inserted into active muscle fibres. However, this approach is not immune to many technical issues and introduces its own pros and cons. More information about implantable electrodes can be found elsewhere.<sup>50,56-58</sup> The motion of the wrist and terminal device are controlled by myoelectric sensors located either at a single site (muscle) or dual sites. Switching between the two different modes (wrist or terminal device) is usually directed by proportional control (fast or slow muscle contraction) or simultaneous control (muscle co-contraction).<sup>55,59</sup> In proportional control, the power of the muscle determines the speed or force of the prosthetic device.<sup>60</sup> Advanced sockets (integrating sensors and metal connections within silicone) and elastomeric liners have helped improve EMG signal acquisition.<sup>55</sup> The incorporation of

programmable microprocessors in myoelectric prostheses increases the adjustment range for EMG signal characteristics and the modification of prosthetic control parameters. Using microprocessors, EMG signals are filtered and a real-time signal analysis is provided. Microprocessors also accommodate pattern recognition-based control, which increases functionality of the prosthesis with higher involvement/input of the user and, in return, decreases the cost and time involved during initial fitting.<sup>59-61</sup>

One major advantage of myoelectric prostheses appears to be its greater range of motion established during functional movement. For example, it executes both opening and closing of the terminal device voluntarily (not exclusively one or the other). Unlike that of a body-powered prosthesis, a myoelectric prosthesis does not require significant body movements or extra space to complete a hand movement. As well, it is not required to be situated in front of an object to manipulate it. Under the control of small electric motors, a myoelectric hand generally allows better grip and pinch than a body-powered hand. Recent models with programmable microprocessors are able to adjust the force applied and perform multiple functions. They can operate sequential movements of the elbow, wrist and terminal device. Myoelectric prostheses carry rechargeable batteries and do not need accompanying cables or harnesses to operate, thus their appearance is more acceptable compared to that of body-powered prostheses.<sup>5,33,48,49(p170),51</sup>

The experimental multifunctional hand with grasp, release, pronation, supination, wrist flexion and wrist extension movements, which utilized EMG signals, was developed in the early 1970s by Herberts et al. In the following years, when tested clinically, it showed higher rates of immediate correct recognition with little training.<sup>62,63</sup> In general, the myoelectric hand improved function and cosmesis, and could be used in a normal, broad range of body positions,<sup>23,30</sup> but whether it had a proportional or ‘on-off switch’ control, lack of sensory feedback was still a drawback. To address this concern, research focused on mechanical vibration or electrical stimulus.<sup>53</sup> A group of researchers from the Control Engineering Group at Southampton University developed a hand with four degrees of freedom and sensory input to a microprocessor controller. The sensors of the Southampton Hand were able to detect contact forces and slippage of an object, and measured the degree of finger flexion.<sup>64</sup> Tura et al, from the Department of Veterans Affairs (US) experimented with force-sensing resistors (FSR) to develop a sensory control system for an Otto Bock hand.<sup>65</sup> In 2002, Light developed a hybrid system hand with two digital signal processors (SAMS and UNB), power electronic drives, and sensors of position, force and slip.<sup>66</sup> Otto Bock’s Sensor Hand, which uses microprocessor technology, monitors the slippage of objects and tells the prosthetic hand to increase grip force.<sup>67</sup> Interestingly, given all these efforts to increase sensory feedback, in Northmore-Ball’s study a higher percentage of the study subjects favored a myoelectric prosthesis over a standard artificial limb with respect to ‘sensory feedback’.<sup>18</sup>

While these technological developments in upper limb prosthetic devices continued to emerge, the most common terminal device fitted to amputees varied across countries. This was partially due to health care delivery systems and methods of payment, but also due to public acceptance of a hook or a hand.<sup>23,68</sup> Public perception varied across countries/cultures. For example, a study from Slovenia showed that 70% of the surveyed upper limb amputees used their prosthesis for cosmetic purposes and a third of the ones wearing a ‘functional prosthesis’ perceived it as a ‘cosmetic aid’.<sup>69</sup> In Kyberd’s survey, 18% of people who identified a *functional problem* with their prosthesis were actually users of a cosmetic prosthesis.<sup>13</sup> According to Lai, the ideal artificial hand should be biomimetic in aspects such as function (motion and forces related with dexterity, grasping, manipulation, and communication), sensing (collecting information from the environment), and external characteristics (weight, inertia, cosmesis).<sup>56</sup> Increasing the number of signal collection sites and utilizing sensory feedback will help achieve better multifunctional myoelectric control.<sup>60</sup> In 1986, Beasley argued that the future of the hand prosthesis would include “mechanically simple devices of socially acceptable appearance.”<sup>47</sup> To date, the technology has certainly advanced in the ‘socially acceptable appearance’ domain, but not necessarily in the ‘mechanically simple’ part of Beasley’s statement. The contemporary myoelectric hand has become more and more complex as new technical features have been introduced.

### *Shortcomings of myoelectric prostheses*

Broad bandwidth and low voltage amplitude are the inherent limitations of myoelectric signals (EMG).<sup>70</sup> Other limitations are the requirement of adequate residual muscle strength (to generate EMG signals with a minimum microvolt threshold), the ability to isolate muscle contractions, and the cognitive ability level required to operate a myoelectric prosthesis. In early clinical versions of myoelectric hands, large numbers of failures and noise during movement were reported.<sup>71</sup> The lighter weight myoelectric hands of the 1980s (e.g. Otto Bock hands with 6V batteries versus the ones with 12V batteries) improved energy saving, but were much slower.<sup>23</sup> Some reported that the mechanical construction of the prosthesis was a limiting factor for manipulation of objects on a horizontal plane.<sup>72</sup> At least one study reported ‘electrical burns’ as an unusual complication of myoelectric prosthesis use.<sup>73</sup> In general, compared to conventional body-powered prostheses, disadvantages of myoelectric prostheses include: increased weight and cost (both upfront and ongoing maintenance costs), less durability during heavy work, susceptibility to easy damage by environmental exposures (mechanical, electrical, chemical), skin problems, heat buildup caused by the socket, technical failures, slower response time, less choice of interchangeable terminal devices, limited sensory feedback, difficulty in learning control of multifunctional myoelectric prostheses, limited number of specialized clinics and experts, and extra work of battery

charging and glove changing.<sup>5,25,48,49(p170),51,74</sup> In the 1990s, for a below-elbow amputee, the cost of a myoelectric prosthesis was about six times higher than the cost of a body-powered prosthesis including an opening or closing terminal device.<sup>32</sup> In 1997, in Canada, the average price of a below-elbow myoelectric prosthesis was \$9000 USD and repair costs of approximately \$800 USD annually. The prosthesis would need replacing every 4-5 years.<sup>45</sup> In 2008, in Canada, the cost of a myoelectric hand ranged from ~\$7500 to \$29500 CAD, whereas a conventional body-powered prosthesis might cost around \$5500 CAD.[Barber J. Prosthetist, WorkSafeBC. email Nov 13, 2008.] Researchers from Brazil reported that they have developed a smaller and quieter myoelectrically controlled biomechanical hand with tri-digital tweezers and a high degree of freedom for finger extension/flexion. Impressively, they were also able to reduce the price to one-third that of imported commercial prostheses.<sup>75</sup>

### *Future of upper limb prostheses*

In the 1960s, the objective for future upper limb prosthesis research was “production of a fully articulated hand capable of several natural finger movements and independent wrist movement”.<sup>76</sup> Today, the goal is defined by many authors as developing “simultaneous, independent, and proportional control of multiple degrees of freedom with acceptable performance and near “normal” control complexity and response time”.<sup>52</sup> For example, a recently developed hand uses 32 surface EMG electrodes and is capable of 12 individual flexion and extension movements of the fingers.<sup>77</sup> Another recent study reports on a force feedback system with stimulation vibration, which leads to a statistically significant reduction in grasping force.<sup>78</sup> Developments in osseointegration (direct skeletal attachment of the prosthetic device), artificial muscles (electroactive polymers) and robotic hands, as well as in implanting electrodes within residual limb muscles, targeted surgical re-innervations, direct neural sensory feedback, artificial neural networks in combination with data gloves, and control of a prosthetic device with cortical and peripheral nerves or mechanomyographic (MMG) feedback are promising areas of development.<sup>55,79-83,160</sup>

## Literature review

### *A few words on the available literature*

- Analyzing and comparing incidence and prevalence rates of amputations is frequently unreliable. Data collection methods vary across countries and even across jurisdictions within the same country.<sup>30</sup>
- Frequently, studies on patients with upper limb prostheses have limited numbers of study subjects. Study teams from different prosthetic rehabilitation centres would do well to collaborate to maximize sample size and enhance the validity of their research. A lack of standard outcome measures frequently restricts this integration and limits the comparison of findings from individual studies.<sup>27,84</sup> Hacking states that in the late 1990s there were no internationally accepted and validated questionnaires for upper limb amputee research.<sup>7</sup> Although standard sets of outcome measures for adult upper limb prosthetic users are still scarce, there are many questionnaires and tests available for pediatric users, e.g. the Child Amputee Prosthetics Project-Functional Status Inventory series, Prosthetic Upper Extremity Functional Index (PUFI), University of New Brunswick Test (UNB Test), and Pediatric Orthopedic Society of North America Questionnaire (POSNA).<sup>84</sup> The Southampton Hand Assessment Procedure (SHAP) and Jebsen Standardized Test of Hand Function are both detailed functional assessment tools for adult amputees. The Trinity Amputation and Prosthesis Experience Scales (TAPES) is another measurement tool for adult populations; it evaluates function, health-related quality of life, and satisfaction with the prosthesis.<sup>84</sup> The Disabilities of the Arm, Shoulder and Hand (DASH) Outcome Measure is a questionnaire designed to measure disability in adults with upper limb disorders.<sup>85</sup> Validation of this tool was performed with nonprosthetic populations.<sup>84</sup> The Canadian Occupational Performance Measure (COPM) and Goal Attainment Scaling (GAS) are individualized measures used in rehabilitation and may be suitable for prosthetic evaluation.<sup>84</sup> A notable instrument for use in adult upper limb amputees is the Assessment of Capacity for Myoelectric Control (ACMC), an observational tool which is deemed suitable for evaluating ‘change’ in the functional capacity of the prosthetic user.<sup>84,86</sup>
- The majority of the studies on upper limb myoelectric prostheses have used questionnaire surveys only.<sup>1,2,4,6-8,11-17,19-22,24,26</sup> Other authors have employed questionnaires in addition to other study methods,<sup>5,9,10,18,23,25</sup> while a number were either clinical/comparative studies or were chart reviews without questionnaires.<sup>3,28,31,87,88</sup>
- Occasionally, studies compare control systems of various prosthetics without keeping terminal devices constant across compared groups.<sup>89</sup>

- Prosthetic studies performed in laboratory settings usually have results based on optimal conditions, rather than real life conditions.<sup>7</sup> Many of the published studies on myoelectric prostheses are based on experimental hands or prosthetic features being studied in research laboratories of the manufacturers/universities. These studies appear to be focused on cutting edge technologies, which are usually not clinically tested. These types of studies<sup>77,78,90-101</sup> are not included in this review.

### *Search strategy*

We did a PubMed and EMBASE search using the keywords ‘amputation, amputee’ AND ‘upper limb, upper extremity, hand, below-elbow’ AND ‘prosthesis, terminal device, myoelectric’ of articles published up to November 19, 2010. The search led to 958 article citations. We excluded articles which contained the keywords ‘congenital, surgical, surgery’. Language was limited to English only. Two hundred and five article abstracts were obtained with these restrictions. All abstracts were reviewed and the full text of relevant articles were collected. We included clinical studies with myoelectric prostheses, comparative studies of various hand prostheses, and reviews on the historical development of hand prostheses, particularly myoelectric prostheses. Studies on conventional body-powered prostheses were excluded unless they reported on vocational outcomes. We focused on studies conducted with below-elbow adult amputees and excluded ones on above-elbow amputations and partial hand amputations (finger replacements, etc.) Studies conducted exclusively with children were not included. Articles focusing solely on ‘measurement tools’ (such as questionnaires or scales) or ‘experimental artificial hands’ (case or simulation reports from technological settings) were also excluded. We scanned the reference lists of the collected articles to spot articles which may have been missed in our database searches. We selected relevant titles from these reference lists, reviewed their abstracts, and added the full text of the ones which met our evaluation criteria to our collection of articles. (Appendix 1) In total, we had 42 articles, of which 5 were descriptive, overview articles on upper limb prostheses. We reviewed in depth the remaining 37. Only one of these 37 studies was a systematic review.

Additionally, using the same search terms, we explored the Cochrane Library, BMJ Clinical Evidence, and Bandolier. We reviewed publications posted on the websites of relevant institutions and organizations such as Health Canada, the US Agency for Healthcare Research and Quality, the NHS Centre for Reviews and Dissemination at the University of York, the US Department of Veterans Affairs, the US FDA, and the Amputee Coalition of America (ACA), as well as conference proceedings from the International Society for Prosthetics and Orthotics (ISPO). To explore health insurance coverage policies on upper limb myoelectric prostheses, we visited the websites of the

other workers' compensation boards in Canada and in a number of US states. We also analyzed the coverage policies in public and private health care insurance systems in various jurisdictions, such as Medicare in the US, MSP in BC, BC PharmaCare, Aetna, CIGNA, and Empire BlueCross BlueShield.

### *Summary and evaluation tables*

A summary table and three evaluation tables of our review are provided at the end of this report (Appendices 3-6).

### *Systematic reviews*

1. **Upper limb prosthesis use and abandonment: a survey of the last 25 years** (Biddiss EA, 2007)<sup>27</sup>

This review by Biddiss and Chau focuses on rejection rates, factors related with abandonment, patterns of wear, function, and consumer satisfaction with upper limb prostheses. They reviewed approximately 200 articles (collected through MEDLINE, CINAHL, EBM Reviews, EMBASE and Ovid Healthstar), of which 40 included prosthesis rejection rates. From each article they extracted data on the study population, methodology, and prosthesis characteristics. They classified studies in three groups based on prosthetic availability and uniformity of experimental conditions: exclusive (subjects were uniformly provided with a single type of prosthesis), uncontrolled (non-exclusive – subjects used a variety of prostheses, but were not uniformly provided with any), controlled (non-exclusive – subjects were uniformly provided with multiple prostheses and were free to choose one according to their needs). They analyzed the differences between subgroups (passive prosthesis, body-powered prosthesis, electric prosthesis, no-prosthesis) using the chi-square test (with Yates' correction). Prosthesis rejection rates were significantly lower in adult populations (26% and 23%) compared to pediatric populations (45% and 35%) for body-powered and electric prostheses, respectively. Incidence of non-wear was similar in children (16%) and adults (20%). A higher acceptance rate for electric prostheses compared to body-powered prostheses was the case for pediatric populations, but not for adult populations. The authors noted heterogeneity of study samples and methodological differences between studies, and they made a series of suggestions for future studies on upper limb prostheses. They recommended multicentre studies and use of standard study tools to help increase generalizability. They favoured controlled study designs to increase comparability. The use of formal statistical methods enabling meta-analysis and evaluation of statistical and clinical validity were also recommended. Multi-factor analysis was proposed as the tool to address different aspects of prosthesis use/acceptance (personal, contextual and technological) and to uncover related main and interaction effects. Development/adoption

of standardized measurement tools and complete descriptive documentation of data and capture of consumer views were also recommended.

### *Clinical studies, surveys and case reports*

#### 1. **Comparison of satisfaction with current prosthetic care in veterans and servicemembers from Vietnam and OIF/OEF conflicts with major traumatic limb loss** (Berke GM, 2010)<sup>161</sup>

The authors analyzed survey data on prosthetic use, collected in 2007-2008 from US veterans who sustained a major traumatic limb loss during the Vietnam conflict (298 veterans) or Operation Iraqi Freedom (OIF)/Operation Enduring Freedom (OEF) conflicts (283 servicemembers and veterans). Subjects participated in the survey either by mail, telephone interview or by accessing a website. In total, 92 veterans were excluded from the presented analysis because they had abandoned or never used their prostheses, or were using a wheelchair for mobility. Eight additional veterans were excluded because of incomplete survey response. Responses from 230 Vietnam and 251 OIF/OEF veterans were studied. The authors used the chi-square test, Mann-Whitney U test, Student's t-test, Fisher exact test, and Wilcoxon rank sum scores for the univariate analyses. The Vietnam participants' average age was 10 years older than the OIF/OEF participants and 78.2% of them were using their prostheses on a participant-defined 'regular basis', compared to 90.5% of OIF/OEF participants. Cumulative prosthetic satisfaction scores were 7.0 and 7.5 for Vietnam and OIF/OEF participants, respectively. For unilateral upper and lower limb loss, amputee satisfaction rankings were higher with private-contract care than with VA care. Vietnam amputees with private care were less willing to 'change their prosthesis to another one' compared with Vietnam amputees receiving VA care ( $p < 0.05$ ). Fewer than half of the participants indicated that they received sufficient information on newly available prosthesis types. Upper limb amputees with transradial level loss were more satisfied compared with upper limb amputees with transhumeral level loss. Overall satisfaction did not significantly differ with levels of amputation for lower limb amputees. Ninety percent of upper limb, 94% of unilateral lower limb, and 95% of multiple limb amputees stated that they were coping with their prosthesis. Ninety percent were able to get repairs; and 67-85% were able to get replacements when needed. Factors correlated with lower prosthetic satisfaction were: poor socket fit, difficulty with repairs/replacements, lack of involvement in prosthetic choice, desire to change to another prosthesis ( $p < 0.001$  for all factors); lack of satisfaction with training ( $p < 0.01$ ), and skin problems ( $p < 0.05$ ). These findings did not change when age (for both Vietnam and OIF/OEF conflict veterans) and sex (for OIF/OEF conflict veterans) were controlled for. The authors concluded that appropriate prosthetic prescriptions based on clinical findings and 'the patient's goals/desires' are critical for successful outcomes following major traumatic limb loss.

2. **Unilateral upper-limb loss: Satisfaction and prosthetic-device use in veterans and servicemembers from Vietnam and OIF/OEF conflicts** (McFarland LV, 2010)<sup>162</sup>

McFarland et al. conducted a cross-sectional study of participants in the national “Survey for Prosthetic Use” (total participants: 581) who had sustained upper limb loss (excluding digit-only losses) during the Vietnam conflict (47) or during Operation Iraqi Freedom (OIF)/Operation Enduring Freedom (OEF) conflicts (50). The response rate for participants from the Vietnam conflict was 65% and for participants from OIF/OEF conflicts was 59%. Their objective was to describe prosthetic device use patterns in these two groups of servicemembers and veterans with combat-associated upper limb loss. The survey questions included: demographics, current military status, employment, comorbidities, injury impact rank, prosthetic type (myoelectric/hybrid, mechanical/body-powered, cosmetic), and satisfaction with the prosthesis. The mean age for Vietnam veterans was 60 years and for OIF/OEF veterans and servicemembers was 30 years. Although the type of comorbidities differed between the two groups, the mean number of comorbidities was similar. The authors used Rasch analysis to assess upper-limb function. Chi-square test, Student’s t-test, Fisher exact test, and Mann-Whitney U test were used for statistical analysis as appropriate. Multiple regression analysis was done using a forward stepwise technique. Seventy percent of the Vietnam group and 76% of the OIF/OEF group were using an upper limb prosthesis. The Vietnam group most commonly used mechanical/body-powered prostheses (78%). In the OIF/OEF group, use of myoelectric/hybrid prostheses (46%) was significantly more than their use in the Vietnam group. Activities of Daily Living (ADL) score was associated with level of limb loss, and increased with more distal losses. Prosthesis rejection or dissatisfaction was associated with type of prosthetic device and with the level of limb loss. Using mechanical/body-powered prosthetic devices was associated with higher upper limb activity, and transhumeral-level limb loss was associated with lower upper limb activity for both the Vietnam and OIF/OEF groups. The authors pointed out that generalizability of the study findings was limited, as the study population included only combat-injury-related limb loss.
  
3. **Prosthetic cost projections for servicemembers with major limb loss from Vietnam and OIF/OEF** (Blough DK, 2010)<sup>163</sup>

Blough et al. conducted a study with members of two limb-loss groups who participated in the national “Survey for Prosthetic Use”: veterans from the Vietnam conflict (298) and veterans and servicemembers from Operation Iraqi Freedom (OIF)/Operation Enduring Freedom (OEF) conflicts (283). The study objective was to estimate the cost of various prosthetic devices based on Medicare 2005 costs and to project future prosthetic costs (for 5, 10, and 20 years, and for lifetime) based on the prosthesis use patterns determined by the survey. The Medicare 2005 cost reference used was the “Fee Schedule Update for

2005 for Durable Medical Equipment, Prosthetics, Orthotics, and Supplies (DMEPOS)” for non-institutional providers. The authors then developed a cost matrix to determine the average cost of a prosthetic device system based on type of prosthetic device, level of limb loss, and functional capacity. They then created a cost file and developed eight Markov’s Models (four for each of the Vietnam and OIF/OEF cohorts) denoting four types of limb loss (unilateral lower, unilateral upper, bilateral upper, and other multiple limb loss). For lower limb loss, they grouped prosthetic device types into six: microprocessor, hybrid, mechanical, sports/specialty, waterproof, and cosmetic. For the level of limb loss they focused on two levels (transtibial or transfemoral), which made up 87% of all lower limb losses. The Medicare Functional Classification Level (MFCL) was used for assigning functional level. For upper limb loss there was no equivalent of MFCL to determine the functional level; hence, they used only prosthetic device types (myoelectric, hybrid, mechanical, and cosmetic) and limb loss levels (transradial or transhumeral – which were the two most common and accounted for 71% of all upper limb losses). They derived the costs for the remaining five levels based on expert opinion. The authors used some assumptions and considerations, including: the functional level at the following year moving based on that of the current year, a 3% discount rate for the dollar’s future value, and the cost of repairs, service, and new prosthetic device technology not being included. They used STATA 9.2 for statistical analysis. Overall, there was significant difference in prosthetic device use between the two limb-loss cohorts (78% of the Vietnam group vs. 90% of the OIF/OEF group). In the unilateral upper limb-loss group, 76% of the OIF/OEF group used prostheses (46% myoelectric and 38% mechanical) and the average 5-year projected cost for upper limb prostheses in the OIF/OEF group was higher than for the Vietnam group (\$117,440 USD vs. \$31,129 USD). The authors concluded that the U.S. Department of Veterans Affairs and other healthcare provider systems should be prepared for increasing costs with emerging high technology devices (e.g. DARPA Arm), which will likely require extra training of the prosthetists, and extra resources to support their use and repair.

4. **The i-LIMB hand and the DMC plus hand compared: A case report** (Van der Niet Otr, 2010)<sup>164</sup>

A group of researchers from The Netherlands conducted a case study with a unilateral upper limb amputee to determine whether the i-LIMB hand – a multi-joint myoelectric prosthetic hand – had more functionality than the Dynamic Mode Control Hand (DMC plus hand), a more conventional myoelectric hand with only a single joint controlling the thumb and two fingers. A 45-year-old man with wrist disarticulation (acquired as a result of a work injury) was tested covering all functional levels of the International Classification of Functioning and Health (ICF) framework. The DMC plus hand was tested first, followed four weeks later by the i-LIMB hand. Although the scores on functionality measured by grip and pinch strength and the Southampton Hand

Assessment Procedure (SHAP) outcomes for the i-LIMB were either lower or the same as for the DMC, the patient was more satisfied with the i-LIMB, as measured by the Trinity Amputation and Prosthesis Experience Scales (TAPES). Visual analogue scale (VAS) scores favoured the i-LIMB for reliability in holding objects and the DMC for its strength and robustness. The authors concluded that the patient should be given the option to choose one or other based on their needs and that the limitations of the i-LIMB should be taken into account for future research in this area.

5. **Multivariate prediction of upper limb prosthesis acceptance or rejection** (Biddiss EA, 2008)<sup>165</sup>

Biddiss and Chau conducted a study which collected data via an international, web-based survey distributed through community-based support groups and rehabilitation hospitals. Their goal was to develop a model for prediction of upper limb prosthesis use or rejection. After excluding incomplete responses and responses from ineligible participants, they had an unbalanced data set of 59 prosthetic rejecters and 132 prosthetic wearers (on average,  $11 \pm 5$  hours prosthetic wear per workday). The survey questionnaire collected data on 36 variables pertaining to individual characteristics, established need, enabling resources, and healthcare utilization. The authors analyzed the data in 5 stages: basic univariate analysis, multivariate modeling, logistic regression, decision trees, and radial basis function networks. The logistic regression model performed better in terms of accuracy and prediction of prostheses acceptance, and was easier to interpret. Beyond some basic results pertaining to individual characteristics and established need (e.g. age, level of amputation), “fitting timeframe” and “degree of involvement in the choice of prosthesis” were the two main factors associated with prosthetic wear in terms of healthcare and enabling resources. People who had prosthetic fittings within two years for congenital and within six months for acquired amputations were 16 times more likely to continue using their prostheses. Also, involvement of the amputee in prosthesis selection increased the likelihood of prosthetic acceptance 8 times. Three factors which were strongly correlated ( $p < 0.01$ ) with prosthesis acceptance – satisfaction with healthcare, satisfaction with prostheses, and high perceived need for prostheses – were not suitable for a priori prediction for prosthetic use in this study setup. The authors pointed out many limitations of this study: its unbalanced sample (more wearers than rejecters), forward stepwise selection of variables (possibility of excluding some important ones), self-selected study sample (not random), more younger amputees than in a typical amputee population (data included from pediatric hospitals), and the likely higher socioeconomic status of participants (all had computer/Internet access) compared to a typical amputee population.

6. **Upper-limb prosthetics: critical factors in device abandonment** (Biddiss E, 2007)<sup>1</sup>

The authors examined predisposing characteristics, established needs, and enabling resources in an anonymous sample of prosthesis users who were reached via the Internet. An online survey was posted on the websites of health care providers, community-based support groups, and the Otto Bock Company. The survey completion rate, ascertained by the number of submitted surveys out of the number of times the survey was accessed, was 40%. Internet Protocol (IP) address was used to identify/filter repeated responses. In 10 months, 266 people completed the survey and 242 were included in the study (average age: 43 years; 51% male). The majority of the respondents were from the US, Canada, and Europe. Sixteen percent of the respondents had limb amputations that were distal to the wrist and 54% were transradial in nature. Fourteen percent had never worn a prosthesis (people with distal to the wrist limb absence and younger children constituted a very high proportion of this group). The prevalence of electric hands and body-powered hooks was similar across the study sample. The chi-square test (with Yates' correction), Student's t-test, Mann-Whitney U test (or Kruskal-Wallis test), and ANOVA were used for the analysis. The authors found that 'level of limb loss' was the most important predisposing factor related with prosthesis acceptance. In the acquired limb loss group, the prosthesis rejection rate was 16% for transradial amputees and 39% for higher level amputees. Dominant hand loss was not related with prosthesis rejection. Females in the acquired limb loss group had higher rejection rates than males. Patients in the 4-10, 24-35, and >65 age groups had higher rejection rates. The authors did not find significant differences in employment rates between people who used and those who rejected their prosthesis. Amputees who rejected their prosthesis were least satisfied with all prosthesis properties (appearance, comfort, ease of control, reliability, and cost). Fitting time frame and patient's involvement in the selection of the prosthesis were also important. Unavailability of health care team support and lack of information provision were related with rejection. The authors listed 'established need' and 'available prosthesis technology' as the most important factors in the use or rejection of a prosthesis.

7. **Survey of Upper-Extremity Prosthesis Users in Sweden and the United Kingdom** (Kyberd PJ, 2007)<sup>14</sup>

Kyberd et al. conducted a mailed questionnaire survey of unilateral upper extremity prosthesis users from three fitting centres in Sweden and the UK. Their goal was to assess prosthesis use/satisfaction from the patient perspective from different countries and to compare groups wearing different types of prostheses. Out of 156 questionnaires mailed, 117 were returned (response rate: 75%). Four respondents were excluded as they were not using a prosthesis. The data from the remaining 113 amputees were analyzed. Twenty-eight percent of the users had more than one prosthesis. Satisfaction was rated using 17 different variables of comfort, functionality, and daily usage (on a 10-point scale). Ratings were standardized for each individual. Results were categorized by type of

prosthesis. Sixty percent of the respondents used a cosmetic prosthesis most of the time. Twenty-seven percent used an electric prosthesis and 13% used another type of prosthesis. Seventy-six percent wore their prosthesis more than 8 hours/day. Electrical prostheses were preferred more often by mid-radius or below amputees. The mean ratings for satisfaction/dissatisfaction were not different for electric and cosmetic prosthesis user groups. 'Function' was more important for electric prosthesis users. 'Appearance' was more important for cosmetic prosthesis users. The authors mentioned that the results from this study could not be generalized, as the amputees recruited from the two prosthesis fitting centres were not fully representative of the general amputee population in these two countries.

8. **Results of an Internet survey of myoelectric prosthetic hand users** (Pylatiuk C, 2007)<sup>19</sup>

The authors conducted an anonymous online survey with German-speaking upper limb amputees who were myoelectric hand users. Their goal was to understand consumer concerns. The survey was available on a non-commercial Internet homepage on hand prostheses ([www.handprothese.de](http://www.handprothese.de)) for four years (2002-2006) and was also presented on several German TV programs on hand prostheses. All questionnaires which had over 50% of the questions answered were included in the study, yielding a sample of 54 study subjects. The authors used the Mann-Whitney U test for the analysis. Answers were analyzed in three groups: males, females, and children. In all three groups the greatest number of amputees were at the trans-radial amputation level. The male and children groups had more congenital cases (56% and 82% respectively) compared to the female group (29%). Females had the highest number of traumatic amputations (71%). The 'weight of the prosthesis' was found to be 'a little too heavy' by 55% of the respondents. The grasping speed of the prosthesis was rated 'too slow' in all three groups (including 76% of males). At least one quarter of all three groups rated the sound of the prosthesis as 'distractive'. In terms of cosmetic appearance, children were more content compared to the two adult groups. Additional features of preference by the amputees using a myoelectric hand were force and temperature feedback, as well as independent thumb, index finger, and wrist movements. This study demonstrated that if a prosthetic hand was worn, it was usually kept on for more than eight hours per day. The authors acknowledged the limitations of the study being an anonymous survey.

9. **A survey of upper-limb prosthesis users in Oxfordshire** (Kyberd PJ, 1998)<sup>13</sup>

The authors' goal was to identify problems encountered by patients regarding the use of various prostheses. They surveyed upper limb amputees who had contacted the Oxford Limb Fitting Centre in the previous 26 months. They designed a four-page questionnaire and sent it to 80 amputees; 56 patients (69%) responded. Seventy-eight percent of those responding were traumatic amputees. 46% of the 56 respondents had below-elbow

amputations. Sixty percent of the 56 respondents made use of body-powered prostheses and 4% had myoelectric prostheses, with the remaining wearing cosmetic prostheses. The effect of the weight, precision, and strength (power) of the prosthesis on prosthetic preference was questioned. The amputees pointed out various concerns related to fit (e.g. sockets, straps, and temperature). Problems with function (mechanical limitations, grip, range, etc.) were mentioned by 60% of the respondents. Interestingly, 18% of these complaints were from cosmetic prosthesis users. Other problems mentioned fell into two categories: appearance and maintenance. The authors concluded that both appearance and function were essential aspects of prosthesis use. The weight of the prosthesis and the colour of the glove were important as well. Eighty-nine percent of the respondents reported wearing their prosthesis daily. Seventy-three percent wore their prosthesis at work. If a prosthesis was worn, it was worn for most of the day. The mean usage time was 13.4 hours/day. The usage time did not correlate with the type of prosthesis, the level of amputation, or with the number of prosthetic problems stated. Special terminal devices were required for sports and leisure activities. Being able to drive was an important consideration for many amputees. The authors suggested that research in this area should consider lightweight materials, long periods of operation (more than 12 hours), easily charged batteries, easy-to-clean gloves, and improved function for future prosthetic designs.

10. **Upper limb traumatic amputees. Review of prosthetic use** (Gaine WJ, 1997)<sup>6</sup>

The authors conducted a retrospective survey to assess the acceptance of limb loss and the success of prosthetic use in traumatic upper limb amputees. They also compared traumatic amputees with congenital amputees. Fifty-five amputees from the Upper Prosthetic Clinic of the Southern General Hospital in Glasgow were studied using a questionnaire, telephone interview, or clinic review. Out of 55, 23 were traumatic amputees (average age: 37) and 32 were congenital amputees (average age: 13). In the traumatic amputees group, the average age at amputation was 28 years and the average duration of follow up was 9.6 years. The authors developed a scoring system, which consisted of points on 'patient satisfaction', 'daily wear', and 'functional level' to assess overall 'prosthetic success'. They found that the overall prosthetic success score of traumatic amputees was poorer than the score of congenital amputees. Further analysis of traumatic amputees showed that amputees who had their initial prosthesis fitting fewer than 12 weeks after amputation had higher prosthetic success and were able to return to gainful employment. In traumatic amputees, loss of the dominant hand did not have a significant impact on prosthetic success. Myoelectric and cosmetic prostheses were favoured for social activities. Myoelectric hands were preferred for light manual tasks and office work, whereas body-powered cable-assisted prostheses were preferred for heavier jobs and farm work.

11. **Long-term outcome of upper limb prosthetic use in the Netherlands** (Hacking HGA, 1997)<sup>7</sup>

Hacking et al. conducted a study of unilateral upper limb amputees who attended a rehabilitation centre in Utrecht, Netherlands for the first time between January 1, 1983 and December 31, 1992. Out of 48 amputees, 39 were surveyed. The postal questionnaire included questions on patient factors (date, cause, and level of amputation, age, sex, pain, hand dominance), prosthesis factors (type, time since fitting, usage profile, cosmesis), and environmental factors (training, educational level, employment status). Responses were received for 29 out of 39 questionnaires sent (response rate: 74%). Fifteen of the 29 respondents had a trauma-related amputation. For the analysis, amputees were divided into three groups based on 'prosthesis wearing time': 'not wearing at all', 'wearing less than 4 hours a day', or 'wearing more than 4 hours a day'. The results demonstrated that amputees with below-elbow amputations wore their prosthesis for longer hours compared to those amputees with through- or above-elbow amputations (with 76% and 50%, respectively, wearing their prosthesis for more than 4 hours/day). Loss of the dominant hand led to a longer wearing time compared to non-dominant hand loss (89% and 40%, respectively, had more than 4 hours/day wear). Out of 17 amputees who believed that their time until prosthesis fitting was acceptable, 14 used their prosthesis regularly (82%). For the group who believed that their initial prosthesis fitting was late, the usage rate was 25%. Seventy-two percent of body-powered prostheses and 78% of myoelectric prostheses were worn more than 4 hours/day, whereas only 54% of cosmetic prostheses were worn for that long. The authors pointed out that they did not find any effect of employment status on prosthesis wearing time. In this study, the prosthesis rejection rate was 21%.

12. **The population of users of upper limb prostheses attending the Oxford Limb Fitting Service** (Kyberd PJ, 1997)<sup>28</sup>

The authors retrospectively studied 334 upper limb amputees who were referred to Oxford Limb Fitting Centre, in the UK, up to February 1992. Their goal was to provide data to help future planning of upper limb provision services. After obtaining a list of amputees from the computer database of the Centre, they retrieved information from individual records on age, gender, cause and level of amputation, and the type of prosthetic supplied. The 'active' study population was defined as amputees who had contacted the centre in the past two years (over 50%). The analysis demonstrated a small increase in prosthesis use by age. They separated the data into three groups based on the amputee's principal prosthesis type: cosmetic hand, working hand/hook (mechanical), or myoelectric hand. If only the 'active' study population was considered, the percentage of people using working devices was higher (52%) compared to cosmetic devices (37%). The authors concluded that the prosthetic user group that attends their Centre most often were men with right-side, trans-radial amputations due to trauma-related injuries.

### 13. **Epidemiologic overview of individuals with upper limb loss and their reported research priorities** (Atkins DJ, 1996)<sup>2</sup>

Atkins et al. undertook an epidemiological study of upper limb amputees in the US (both adults and children). Their goal was to establish a national database of upper limb loss patients and to evaluate the use of prostheses, trends in technology and the preferences of prosthetic users. They first developed survey instruments through two pilot studies, then collaborated with 104 entities located throughout the country (such as physicians, rehabilitation facilities, the Veterans Administration, hospitals, and prosthetic manufacturers) to identify upper limb amputees. They sent out a one-page survey to more than 6600 amputees; 2477 were returned. They then sent a longer survey to those respondents. The longer survey had three different versions sent to three different groups based on the type of prosthetic they used. Data were collected on gender, age, amputation (level, etiology, and side involvement – unilateral/bilateral), type of prosthesis, components used, therapy and rehabilitation experiences, funding, maintenance/repairs, functional abilities, and preferred prosthetic enhancements. In total, 1575 amputees responded to the second survey (64% response rate). Of these 1575 individuals, 1020 had unilateral body-powered prostheses, 438 were unilateral electric prosthesis users, and 117 patients had bilateral prostheses. The authors analyzed the data from these three groups separately. The mean age was higher in the body-powered prosthesis user group compared to the electric prosthesis user group (32.1 vs. 24.9 years) and there were more adults in the electric prosthesis user group (61% vs. 18%). In both groups, transradial amputation was the most common amputation level (48% of body-powered and 53% of electric prosthesis users). Cables needed repairs most often in the body-powered prosthesis group. In the electric prosthesis user group, gloves needed repairs more often. The results showed that transradial amputees using a body-powered prosthesis wanted a terminal device rotated by the wrist, with a coordinated motion of two joints: the wrist moving from side to side and up and down. Transradial amputees using an electric prosthesis desired improvements in finger bending, thumb movement out to the side, and with a thumb able to touch each finger individually. A device requiring less visual attention would be preferable. In summary, for electric prosthesis users, short-term priorities included improved gloves and batteries/charging units, and more reliable electrodes; whereas long-term priorities were greater range of finger movements, reduced requirement for visual attention, and improved wrist movement. The authors recommended a number of key points be addressed in future prosthetic research:

- data from different age groups (children, teenagers, adults, seniors) should be analyzed separately
- for each functional task, an ‘activity analysis’ should be undertaken (explaining properties of grasp and prehension) and each functional task should be evaluated using each prosthetic type

- during the survey, written commentaries (beyond the survey questions) should be obtained from the amputees and should be analyzed using qualitative methods.

The information collected (including direct access to parts of the data set) should be shared with medical professionals, patients, and families.

**14. The long-term outcome of upper limb amputees treated at a rehabilitation centre in Sydney, Australia (Jones LE, 1995)<sup>11</sup>**

Jones and Davidson reviewed charts from the Rehabilitation Centre of the Royal South Sydney Hospital, Australia for the 1981-1990 period. Their goal was to assess long term prosthetic use and functional capacity of treated patients. The review yielded 41 major upper limb amputees of whom 4 had died by the time of the review. Hence, the study population contacted was 37 adult amputees (by postal or in person questionnaires). Twenty-seven amputees responded (response rate: 73%). The ten non-respondents were younger than the mean amputation age of 36 at their time of amputation. All 27 respondents had been prescribed a prosthesis (body-powered or cosmetic) after amputation. Out of 27, 37% were regular prosthesis users, 19% were occasional users, and 45% were non-users. The reasons stated for not wearing a prosthesis were related with the prosthetic (e.g. causing sweat or being cumbersome). The number of people who were retired or unemployed was twice as many during the survey compared to that at the time of amputation. All unemployed people were non-users. The study authors concluded that prosthetic usage was related to the level of amputation, and that distal amputees had higher usage rates.

**15. Prosthetic usage in major upper extremity amputations (Wright TW, 1995)<sup>26</sup>**

Wright et al. from the Mayo Clinic (Rochester, MN, USA) conducted a review study of major upper limb amputations. They reviewed the charts of 330 upper limb amputees who attended their clinic between 1975 and 1987, and provided them with short answer questionnaires. Out of 150 respondents, 135 met the inclusion criteria of ‘major upper extremity amputation’ (wrist or more proximal). The authors’ goal was to evaluate patterns of prosthetic use. The mean age of the study sample population at amputation was 36 years and for 72% of these patients the cause of amputation was trauma. Forty-four percent of amputations were below-elbow. The average follow up was 12 years. Eighty-four percent (113 out of 135) were fitted with myoelectric or body-powered prosthetics. The authors did not find a correlation between prosthesis fitting time (more or less than 1 year after amputation) and prosthetic use patterns. No correlation existed between the age at amputation and prosthesis usage. The prosthesis rejection rate was 38%. Reasons given by the amputees for non-usage included various technical and functional limitations of the prosthesis. For example, limited shoulder motion range was significantly related with prosthetic rejection ( $p < 0.05$ ). The prosthetic usage rate of below-elbow amputees (94%) was the highest among all levels of major upper extremity

amputations, and 100% of the bilateral amputees surveyed used their prostheses. Loss of dominant limb was also significantly related to increased usage. The employment rate after amputation was 78%; being female and having stump pain affected the employment rate negatively. The overall prosthetic acceptance rate was 62% and it was 100% for the five below-elbow amputees with myoelectric prostheses. The authors concluded that below-elbow amputees predictably would use their prostheses regularly, and therefore should be prescribed one after amputation, whereas above-elbow amputees or amputees with a stiff shoulder or brachial plexus injury are less likely to use their prosthesis.

**16. Functional outcome following traumatic upper limb amputation and prosthetic limb fitting (Pinzur MS, 1994)<sup>88</sup>**

Pinzur et al. conducted a retrospective review to evaluate prosthetic use and functional rehabilitation of traumatic upper limb amputees. They included 19 consecutive amputees from their Level I Trauma Centre over a 9-year period. Ten had transradial amputations, 6 had transhumeral amputations, and 3 had shoulder disarticulations. Eighteen out of 19 were fitted with prostheses and 15 of them had early preparatory functional limb fitting in the first 30 days following amputation. The preparatory functional limb was a body-powered cable-driven prosthesis. Seventeen out of 18 amputees fitted with prostheses became proficient users. Functional outcome with the preparatory prosthesis was excellent, especially for transradial amputees, hence they were fitted with a myoelectric prosthesis as soon as the volume of the residual limb was stable enough to fit a socket. Follow up examinations were conducted on average 52 months after the prosthetic fitting. At amputation time, out of 19 study subjects, 18 were employed; after amputation, 4 of them were not able to return to the workforce. Out of these 4, only 1 was a transradial amputee. Nine out of 10 transradial amputees were able to use their prosthesis for functional prehension. The authors concluded that a high percentage of traumatic amputees could use their prostheses functionally and could return to work; activity level and residual or phantom limb pain is not a big barrier for successful rehabilitation.

**17. Consumer concerns and the functional value of prostheses to upper limb amputees (Kejlaa GH, 1993)<sup>12</sup>**

Kejlaa reviewed all amputation registers in the county of Funen, in Denmark, for the period of January 1900 to December 31, 1987. Out of 105 upper limb amputees recorded, 66 were included in the study (32 were dead, 7 did not participate). Sixty-five percent of the amputations were trauma related. The other major group included those amputations due to congenital deformities (15%). Seventy-seven percent of the 66 patients had transradial amputations. Kejlaa's goal in this study was to evaluate concerns of prosthesis users and to see how these concerns may have affected prosthetic use patterns and to also undertake an estimate of the functional levels of prosthetic users and non-users. The author visited all amputees at their homes and collected data using a questionnaire. The

mean age at amputation was 24.5 years and the mean age of the patients during the study was 45.1 years. The amputees were categorized into four groups based on prosthesis usage: active, partially active, passive and non-users (active: prosthesis use >8 hours/day, partially active: prosthesis use <8 hours/day, only passive prosthesis use, no prosthesis use). Active and partially active users were younger. Out of 32 active prosthetic users, seven were using myoelectric prostheses and were employed in office work or were students. Heavy workers preferred a conventional mechanical prosthesis (generally a hook). Amputees with myoelectric hands mostly complained that the prosthesis was hot, heavy, and the glove got dirty easily. When ADL tasks were evaluated, it was found that 'active users' had significantly fewer task problems than the amputees from the 'passive' and 'no prosthesis' groups. The author concluded that myoelectric prostheses were preferred for their cosmesis and by amputees with clean and light work conditions. He also suggested that the time lapse between amputation and initial prosthesis fitting should not exceed six months.

18. **Myoelectric prostheses. A long-term follow-up and a study of the use of alternate prostheses** (Silcox DH, 1993)<sup>22</sup>

Silcox et al. conducted a long-term follow up study to examine acceptance and usage of myoelectric prostheses (or alternate prostheses) and associated demographic factors of the amputees. In Emory University affiliated hospitals, from January 1979 through December 1989, 61 patients were fitted with a myoelectric prosthesis. To be included in the study amputees had to have been using a myoelectric prosthesis for more than two years. With 14 patients lost to follow up, one dead and two with less than two years' experience, the number of study subjects included was 44. The mean age at prosthesis fitting was 38 years. Ninety-one percent of the amputations were trauma-related. Sixty-eight percent were distal to the elbow and 6% were wrist disarticulations. Out of 44, 40 owned a conventional prosthesis and nine owned a cosmetic prosthesis besides their myoelectric prosthesis. Out of the 40 who owned a conventional prosthesis before being fitted with a myoelectric prosthesis, 83% were well experienced, on average using their prosthesis for 8 years. The authors utilized a standardized questionnaire to determine prosthetic usage patterns, reasons for rejection, training received, and the amputee's perception of sensory feedback. Amputees were asked to quantify the time they spent wearing their various prostheses at home, at work, and for social activities, and were assigned 0 to 4 points, based on their usage time. The authors analyzed the results using the chi-square test with Yates' continuity correction, Spearman's rank correlation test, regression analysis, or ANOVA, with an alpha value of 0.05. Myoelectric prosthesis and conventional prosthesis usage were negatively correlated ( $r_s = -0.44$ ,  $p \leq 0.004$ ). There was no association between myoelectric prosthesis acceptance and training by an occupational therapist. They found no significant association between acceptance of myoelectric prosthesis and length of prior experience with a conventional prosthesis.

Amputees whose job required light demands from their prosthesis found sensory feedback good and the ones with high prosthesis demand jobs found sensory feedback poor. No correlations were found between the use of any type of prosthesis and age/sex of the amputee, reason for amputation, length of time until the prosthesis fitting, or prosthesis type preferred. There was a relationship (but not significant) between usage and occupation; white-collar workers used myoelectric prostheses more than blue-collar workers. The reasons often brought up for not utilizing a myoelectric prosthesis were its heavy weight, low durability, and relative slowness. The rejection rate for myoelectric prostheses was 50%. The most common reason for usage of a myoelectric prosthesis was its cosmetic appearance.

19. **Functional benefit of an adaptive myoelectric prosthetic hand compared to a conventional myoelectric hand** (Bergman K, 1992)<sup>3</sup>

Bergman et al compared an adaptive myoelectric hand (ES Hand) with a conventional myoelectric hand (Otto Bock 8E38=7 ¾) in terms of prosthetic function and preference. Eight consecutive patients from a prosthetic clinic (Linköping University Hospital, Sweden) agreed to participate (median age: 39.5 years). They were regular non-adaptive myoelectric prosthesis users (median time since first myoelectric prosthesis: 3.5 years) with a unilateral traumatic amputation. Seven were below-elbow amputees. They were all fitted with an adaptive myoelectric hand and were instructed to use it as much as possible during the first two months. For the next ten months, they were allowed to use both prostheses. Adaptive hands were initially developed to allow for a more human-like grip. The second and third fingers continue flexion (via wires arranged like tendons) until stopped by the gripped object. Flexion of the thumb is also motorized and activates concurrently with fingers. To evaluate prosthetic function the authors used the standardized grip function test developed by Sollerman, which consists of 20 different ADL tasks. They assessed each patient with both prostheses, during three different sessions. The highest scores obtained from these three sessions were used for the analysis. They tested differences between the two prostheses using Wilcoxon's signed-rank test. Test scores with conventional myoelectric hands were significantly better than the scores with adaptive hands ( $p < 0.01$ ). Two independent observers marked the grip function test, and the interobserver correlation (Spearman's rank correlation coefficient) was high,  $r_s = 0.97$ . They also tested the two prostheses technically. Width and force of grip were significantly greater with the conventional myoelectric hand compared with the adaptive hand. Maximum circumference of the closed hand and weight of the hand were less for the conventional myoelectric hand. For further prosthetic use, all patients preferred the conventional myoelectric hand over the adaptive hand.

20. **Prosthetic rehabilitation of upper limb amputees: a five year review** (Datta D, 1991)<sup>4</sup>

Datta and Ibbotson reviewed 55 upper limb amputees who attended a regional referral centre in Sheffield, UK for the first time between January 1, 1984 and December 31, 1988 and had at least two years of follow up. Ninety-six percent of the amputees were provided with prostheses. Out of 55 amputees, 20 were adults. Twenty-two were below-elbow amputees and 10 were trauma-related amputations. The authors used postal questionnaires, telephone interviews, and case-note reviews. Out of 55, 35 amputees (all with prostheses, not deceased, and not lost to follow up) were sent questionnaires. Information on electrically-powered prosthesis users (7 amputees) was collected through another recent study by the authors. Wearing patterns for the non-electrically powered prosthesis users ranged from 1-9 hours/day and 2-7 days/week, with a higher wearing time in the below-elbow amputee group. For the electrically-powered prosthesis users, wearing patterns were 6.6 hours/day and 6-7 days/week. Sixteen amputees were identified as 'employable', though only seven of them were employed (43.7%), with six of seven using their prostheses. Four were unemployed and three of them had abandoned their prostheses. Prior to their contact with the centre, 70% of the amputees received very little counseling and information. The prosthesis rejection rate was 27.2%. Loss of non-dominant arm, higher level of amputation, other disabilities, unstable family circumstances, and delay in referrals to rehabilitation centres were likely to increase rejection of the prosthesis.

21. **Early upper-extremity prosthetic fit in patients with burns** (Fletchall S, 1991)<sup>31</sup>

This study reports on seven patients from the Regional Medical Centre in Memphis, Tennessee, who required amputations following burns (between December 1986 and March 1989). The mean age of the patients was 37.4, the average 'total body area of burn' was 17.85%, and the average length of stay at the health centre was 30.14 days. Occupational therapy started on the first day of admission, including pre-amputation edema control, burn treatment, and education on future functional abilities. They conducted an in depth assessment prior to the amputation. This included assessment by a surgeon and an occupational therapist, evaluating the remaining muscle function, possible sites for myoelectric prosthesis use, range of motion, pre-burn home, and vocational and avocational responsibilities. Following the team's assessment, the patient and the family were informed about the rationale for amputation, the prosthesis, the training period, and follow up in the future. Six of the patients had below-elbow amputations (one being bilateral). Four of the patients were fitted with a prosthesis immediately after the amputation (three body-powered, one myoelectric), and three patients were fitted with a prosthesis in the first 30 days after amputation (one body-powered, one myoelectric, and one electronic system). A permanent prosthesis was fitted two to three months after the temporary one. By the end of the first two weeks after the prosthesis fitting, all seven amputees were able to manage self-care activities (feeding oneself, maintaining hygiene,

using the toilet with no assistance). The time for managing pre-amputation activities (daily living, home making, driving, avocational activities) was 2.5 months on average, and from the date of injury to return-to-work took 6.4 months on average. The authors concluded that upper extremity amputees (due to burns) benefit from early prosthetic fitting.

22. **Proportional myoelectric hand control: an evaluation** (Sears HH, 1991)<sup>21</sup>

A telephone survey was conducted to study proportionally controlled myoelectric hands, which generate a motor voltage (hence, speed and force) proportional with the actual EMG signal strength coming from the user's residual muscles. The authors studied usage patterns of proportional myoelectric hands. They compared these patterns with those of the amputee's previous prosthesis in terms of quickness, control of speed and force, required effort to open/close the terminal device, comfort (weight and bulkiness), convenience (battery life and reliability), and cosmesis. The lead investigator of the study was affiliated with Motion Control Inc., a well known manufacturer of myoelectric and externally powered prosthetic arms. For the study, they contacted 48 patients who had been prescribed the Utah proportional hand control system. Thirty-three patients participated after 8-9 months of proportional myoelectric hand use. There were three groups of amputees: former digital myoelectric hand (with on/off switch) users (14), former body-powered terminal device users (5), and amputees with no previous prosthesis (14). Twenty-one of 33 patients were below-elbow amputees. Interview questions were answered based on a 5-level scale (much better, better, same, worse, much worse; from +2 to -2). To identify significant differences between the previous and current prosthesis, data was analyzed by Student's t-test. Former digital myoelectric hand users wore the proportionally controlled myoelectric hand longer hours and gave the highest overall rating to this new hand. For this group, 'control of speed and pinch force' was the most valuable feature. They valued 'quickness', 'control', and 'lower effort' as well. Disadvantages mentioned were 'weight' and 'inconvenience'. A subset of the first-time prosthetic users, who received some training, was better in assessing the value of the proportionally controlled hand compared to the ones who did not receive training.

23. **Myoelectric prostheses for below-elbow amputees: the Trent experience** (Datta D, 1989)<sup>5</sup>

The authors invited 43 myoelectric prosthesis users, who were fitted in the Nottingham Centre, UK, for a follow up study. Thirty-seven amputees, of whom 14 were adults (age: > 16 years), participated. Only 8 of the 14 had trauma-related amputations. The aim of the study was to assess amputee characteristics (arm dominance, stump, other disability), prosthesis characteristics (types of hardware, technical problems, weight, discomfort), and rehabilitation outcomes (rejection or usage pattern, performance task test, activities of daily living (ADL), employment). The prosthesis rejection rate was 17% in adult

amputees and 31% in the younger age group. Seventy-seven percent of adult amputees were independent in activities of daily living. Employment rates were high for the adult myoelectric hand users (90%). The authors recommended a multidisciplinary approach and specialized/comprehensive facilities for rehabilitation with myoelectric prostheses. They also suggested widening the scope of social, occupational, and recreational activities of amputees, and provision of a body-powered prosthesis along with a myoelectric hand.

24. **Factors related to successful upper extremity prosthetic use** (Roeschlein RA, 1989)<sup>20</sup>  
Roeschlein and Domholdt evaluated factors affecting success in upper limb prosthetic use and, specifically, focused on the effect of the prosthetic type. They identified 86 long-term upper limb amputees through prosthetic stores and prosthetists, and applied a 75-item questionnaire. The main topics addressed were: demographic/personal info, amputation-related factors, ADL, reliability and durability of prosthesis, and general concerns about the prosthesis. Out of 86 questionnaires, 48 responses were returned (response rate: 56%). Eight had missing data; hence, the analysis was based on the remaining 40 (mean age at amputation: 30.8 years). They used chi-square analysis with a significance level set at 0.10 or less. Seventeen of 40 patients were below-elbow amputees. Only three out of a total of 60 prostheses (multiple prosthesis use) were electrically powered prostheses. Amputees were divided into three groups based on their prosthetic use. ‘Successful’ amputees were users of at least one type of prosthesis every day, throughout most of the day. ‘Partially successful’ amputees used their prostheses for certain tasks or hobbies, and ‘unsuccessful’ ones either did not use a prosthesis or used it only for cosmetic purposes. The authors stated that ‘acceptance of amputation’, both at the time of amputation and during the interview, had an effect on prosthetic success. Education and employment status at amputation, time between amputation and prosthetic fitting, number of existing medical conditions prior to prosthetic fitting, and perceptions about prosthesis cost were related with success. Loss of dominant hand, level of amputation, use of temporary prosthesis, and prosthesis training were not related with successful prosthetic use. Median return-to-work time was six months for successful prosthesis users compared to 12 months for partially successful or 36 months for unsuccessful users.
25. **Traumatic amputation of the upper limb: the use of body-powered prostheses and employment consequences** (Sturup JHC, 1988)<sup>24</sup>  
Sturup et al. interviewed 43 upper limb traumatic amputees regarding their prosthetic use and employment consequences. Out of 59 patients attending the Department of Surgery, Copenhagen (Denmark), 12 were lost to follow up and one cosmetic and three myoelectric prosthesis-wearing patients were excluded. All of the study subjects had body-powered prostheses. The mean age at amputation was 30 years and the mean follow

up was 7.4 years. The authors analyzed the data with the chi-square test. At the time of the interviews, the mean age of the prosthetic users was 38 years, higher than the mean age of non-users (which was 32 years). Fourteen amputees never used their prosthesis, 15 used it all day, while four used it occasionally. Below-elbow amputees had a higher usage rate compared to above-elbow amputees (90% and 50% respectively,  $p < 0.01$ ).

Interestingly, during the interviews, the employment rate among non-users (mostly at skilled and non-strenuous jobs) was higher than the rate for prosthetic users (57% versus 37%). This difference was not statistically significant and was probably related to the type of occupation pre-amputation. Sex, stump pain, time between amputation and fitting, and follow up were not related with the amount of prosthetic use time.

26. **Prosthetic use in adult upper limb amputees: a comparison of the body powered and electrically powered prostheses** (Millstein S, 1986)<sup>17</sup>

Millstein et al. retrospectively reviewed 314 unilateral upper limb amputees, all of whom sustained work-related injuries and were treated at the Ontario Workers' Compensation Board Amputee Clinic. The mean age of the study group was 49 years and the mean age of amputation was 34 years. The authors administered a standard questionnaire and reviewed the records of the amputees. The goal of the study was to assess both function and acceptance of various body-powered and electrically powered prostheses in amputees with different amputation levels. Most of the amputees owned a number of different types of prostheses. Two hundred and twenty of them were below-elbow amputees. Seventy-two of these were originally fitted with an electrically powered prosthesis and 82% were still using it at the time of the study. The reasons for the high acceptance rate of electrically powered prostheses included: comfort (no harness for below-elbow), cosmetic appearance, superior pinch force, more natural control, and elements of sensory feedback between the stump and the prosthesis. However, the high cost of initial fitting and intermittent repairs, the need for a specialized prosthetic service centre, insufficient durability, and regular battery recharge were listed as disadvantages. According to the results of this study, amputees working in an office, in supervisory work, or in jobs requiring public contact preferred an electrically powered prosthesis; whereas amputees working in heavy jobs (handling dirty, greasy, or sharp materials, or engaging in heavy lifting) or in extreme weather conditions (very cold or very hot/humid weather) preferred body-powered hooks over myoelectric hands. The authors suggested that most upper limb amputees should be fitted with both a body-powered and an electrically powered prosthesis. They also concluded that patient follow up and service in a multidisciplinary team environment contributed to the positive findings observed in this study.

27. **Electrically powered prostheses for the adult with an upper limb amputation** (Heger H, 1985)<sup>8</sup>

The authors reviewed 164 adult upper limb amputees (mean age: 39 years) who were fitted with electrically powered prostheses between 1974-1981 at the Workers' Compensation Board Hospital and Rehabilitation Centre in Toronto. Out of 164, 130 were below-elbow amputees. All were fitted with Otto Bock myoelectric hands. During the study, the authors reviewed the patients' records and implemented a standard questionnaire. Out of 130 below-elbow amputees, 104 stated that they made use of their myoelectric hands either exclusively for primary use or for both primary and secondary use. The author notes an 80% acceptance rate for below-elbow amputees. The acceptance rate for above-elbow amputees was 69% and for high-level amputees was 72%. The authors did not find evidence for any relationship between acceptance of the electrically powered prosthesis and age, time since injury, or previous use/rejection of a cable-controlled prosthesis. Factors leading to acceptance included: comfort, function, and reasonable appearance of the prosthetic hand; suitable occupation; and dislike of harness. Disadvantages leading to non-acceptance of the prosthesis were: unsuitable working conditions, fear of damage to the prosthesis, and insufficient function and/or appearance.

28. **A review of employment patterns of industrial amputees – factors influencing rehabilitation** (Millstein S, 1985)<sup>15</sup>

To determine the employment status of worker amputees from the Amputee Clinic of the Ontario Workers' Compensation Board and to explore the factors affecting successful return to work in order to better direct treatment programs in the future, Millstein et al. undertook a review study. They designed a questionnaire and pre-tested it at the Amputee Clinic. The revised version of the questionnaire was mailed to all 1683 amputees (with upper, lower, or multiple limb amputations) compensated by the Ontario Workers' Compensation Board between 1917 and 1981. Questions inquired about demographic status, employment status (pre/post amputation), and prosthetic use. Ninety-six people were eliminated due to unknown address or death. Of the remaining 1587, 1010 completed and returned the questionnaire (response rate: 64%). The average follow up after amputation was 14 years. When the review was conducted, 51% of the amputees were working full-time, 5% were working part-time, 25% were retired, and 8% were unemployed. The rest were not seeking employment – they were either recovering or involved in a vocational process. The authors used SAS software for their statistical analysis. They assessed the amputation level of a random sample of the amputees who did not respond and found that there was no statistically significant difference between the respondents and non-respondents. Their analysis compared three different amputation categories: upper limb, lower limb, and multiple amputations. The retirement rate was highest in the group with multiple amputations and lowest in the group with upper limb amputations. In general, the unemployment rate was 2.5 times higher in females, and the

older a worker was at the time of amputation, the less likely they were to return to work. Below-elbow amputees made up 30% of all amputees. Among upper limb amputees, the unemployment rate varied by the level of amputation; the highest (22%) in above-elbow, the lowest (10%) in below-elbow, and 18% in partial hand amputations. Subjects who reported more frequent prosthesis use were more likely to be employed. Dominant hand loss was not found to be related with unemployment rate. Although they did not assess the psychological state of the amputees, the authors emphasized the importance of psychological circumstances as a factor influencing the success of a rehabilitation program, and subsequent return to work rates. Study subjects stated that their 'own attitude' and 'own skills' had a major impact on their return to employment. The authors concluded that for a successful return to work, programs combining medical, prosthetic, and vocational services should be implemented.

**29. Functional comparison of upper extremity amputees using myoelectric and conventional prostheses (Stein RB, 1983)<sup>23</sup>**

Researchers from the Department of Physiology and Occupational Therapy at the University of Alberta conducted a study to compare the performance of patients with myoelectric hands, conventional prostheses (cable-controlled hook) and normal hands. Between 1978 and 1980, 36 upper extremity amputees (20 myoelectric and 16 conventional prosthesis users), of whom 24 were below-elbow amputees, were studied. The average period of prosthetic use was 1.4 years for myoelectric hands and 12.2 years for conventional prostheses. To address this discrepancy, the authors analyzed for any correlation between the period of prosthetic use (since initial prosthetic fitting) and functional measures of prosthetic use. They reported no significant correlation. The authors employed functional range of motion (ROM) tests as well as a questionnaire on activities of daily living (ADL). They used arithmetic mean and unpaired Student's t-tests for the analysis of the majority of the variables. For some ROM variables with skewed distributions, they employed a geometric mean. Conventional prostheses were worn 14 hours/day on average, compared to myoelectric hands that were worn 9.6 hours/day on average. This difference was found to be statistically significant at  $p = 0.01$ . On average, the ROM scores of myoelectric users were higher than those of conventional prosthesis users (4.3 and 3.6, respectively). However, when using a myoelectric hand, tasks were found to take twice as long compared to a conventional prosthesis and 5 times longer compared to a normal hand. The authors explained the slow speed by the low voltage of the battery (6V) in use at that time. The average scores on the ADL questionnaire were not different for myoelectric and conventional prosthesis users. Although fitted with both, 60% of the below-elbow amputees chose to use the myoelectric prosthesis over the conventional one. The authors concluded that (at least for below-elbow amputees) myoelectric hands should be considered as part of appropriate health care practice and financial consideration for full funding would appear to be in order.

30. **A field evaluation of arm prostheses for unilateral amputees** (van Lunteren A, 1983)<sup>25</sup>

The authors conducted a post-clinical field study with 42 unilateral amputees who were treated in two rehabilitation centres in the Netherlands. Data was collected for the 1977-1978 period. All amputees lost their hands due to traumatic accidents. Thirty of 42 were below-elbow amputees and 15 had myoelectric hands. Quantitative data included medical data and results from psychological tests, an ADL questionnaire, and a multiple choice questionnaire. Qualitative data was from interviews during home visits. They analyzed 26 items from the ADL activities list in more detail and found that during these activities, gripping function was used more by the myoelectric hand users compared to the body-powered hook/hand users (significance level 0.02). Out of 38 amputees (4 of the 42 were not using a prosthesis at all), 28 mentioned that their prosthesis was important for hobbies, 17 mentioned driving or cycling, 14 mentioned work, and 6 mentioned ADL. Out of 13 amputees who were originally fitted with a myoelectric hand, 12 were still wearing a myoelectric hand during the field study. Out of 24 amputees who were originally fitted with body-powered hand/hook, only 10 were still using a body-powered prosthesis. Six of the 24 had switched to a myoelectric hand. Amputees wearing a myoelectric hand were using their prosthesis more frequently compared to amputees wearing a body-powered prosthesis. One advantage of the myoelectric hand, often mentioned by below-elbow amputees, was its lack of harness. On the other hand, its lack of sensory feedback and dependence on visual feedback was mentioned as a disadvantage.

31. **Clinical evaluation of myoelectric prostheses in below-elbow amputees** (Herberts P, 1982)<sup>9</sup>

Sixteen below-elbow amputees in Goteborg, Sweden, were fitted with myoelectric hands between 1975 and 1978 as part of the myoelectric prosthesis program. To critically evaluate the results and efficiency of these myoelectric prosthetic fittings, the prosthesis team conducted a follow up study in 1979. They did ADL tests in the laboratory, implemented an extensive questionnaire, and conducted a technical check-up of the prosthesis. They noted that nine of the sixteen who were originally fitted with a myoelectric prosthesis were still wearing it, three were using a cosmetic prosthesis, two were using a hook and two were not using a prosthesis at all. The authors pointed out that the 56% acceptance rate for a myoelectric hand was good compared to the 23% acceptance rate for a conventional prosthesis (before the myoelectric prosthesis program started, 22 patients were fitted with a conventional prosthesis). During the myoelectric prosthesis program, five amputees were fitted with the three-function myoelectric SVEN-hand, which was controlled by a pattern recognition method. Although all five patients agreed that this type of prosthesis control was easy and reliable, and all valued the additional movements (i.e. pro-supination and wrist extension/flexion), the mechanical problems with the SVEN-hand outweighed its excellent control system. The authors

concluded that ‘good prosthesis acceptance’ figures will rely on a rehabilitation program implemented by a skillful team and a proper follow up. They argued that providing an identical, spare prosthesis may also be helpful. They felt confident that microcomputer applications will simplify fitting procedures and will introduce proportional control.

32. **A review of the failures in use of the below elbow myoelectric prosthesis** (Millstein S, 1982)<sup>16</sup>

By September 1981, the total number of below-elbow amputees who had been fitted with a myoelectric prosthesis (6-12 months after surgery) at the Ontario Workmen’s Compensation Board Hospital and Rehabilitation Centre was 128. Each patient was also provided with a cable-operated prosthesis (both a hand and a hook). A group of 25 patients (mean age: 41 years) had either returned their myoelectric prosthesis voluntarily (5), or had failed to return for an interview (6), or had stated rejection or rare use of their myoelectric prosthesis (14). After a mean 33 month period, 3 of these 25 patients were lost to follow up. The remaining twenty-two were reviewed using a standardized questionnaire (telephone or in person interviews). Sixteen of the 22 were unilateral amputees and six were bilateral. Sixty-three percent had a dominant side amputation. For the analysis, the 22 patients were divided into two groups: 10 limited users and 12 non-users. The researchers measured the degree of acceptance of prosthesis in terms of function (activities of daily living and vocational/non-occupational activities), cosmesis, and comfort. They compared findings from myoelectric prosthesis and cable-operated prosthesis users. Both non-users and limited users declined to use their myoelectric prosthesis at work because of concerns with damaging it. The vast majority (84%) used their cable-operated hooks at work. Eighty percent of limited users were concerned about cosmesis, whereas only 33% of the non-users were. Limited users indicated a high cosmetic value for the myoelectric prosthesis when used during social events. Half of the amputees from both the limited user and non-user groups mentioned the weight of myoelectric prostheses as a problem. The major reason for rejection of the myoelectric hand in the non-user group was its poor functional value. The authors suggested that a myoelectric hook (instead of a hand) might be a solution.

33. **Functional effectiveness of a myo-electric prosthesis compared with a functional split-hook prosthesis: a single subject experiment** (Agnew PJ, 1981)<sup>29</sup>

The author compared a myoelectric prosthesis with sensory feedback to a split hook device (Hosmer-Dorrance split hook). This is a single case study, with one female post-traumatic below-elbow amputee, who was 34 at the time of accident (1975). She became an experienced user of the split hook and then volunteered to be fitted with a myoelectric hand with sensory feedback (1978). Two testing sessions per day were undertaken wearing each prosthesis during the 30-day study period. The tests used in determining functional effectiveness were the Minnesota Rate of Manipulation Placing Test and the

Smith Test of Hand Function. The order of the tests and prostheses was randomized. The author used a first order autoregressive model for the analysis and found that the split hook was functionally better than the myoelectric prosthesis ( $p < 0.001$ ). However, she noted that based on clinical evidence, the myoelectric hand with sensory feedback was valuable and was preferred for executing certain tasks.

34. **Rehabilitation of unilateral below-elbow amputees with myoelectric prostheses** (Herberts P, 1980)<sup>10</sup>

Herberts et al. studied 38 unilateral below-elbow amputees in the Department of Orthopaedic Surgery, Goteborg, Sweden. Sixteen of the amputees obtained training after their first myoelectric prosthesis application and 22 were untrained. After one to four years follow up (mean 2.4 years), nine of 16 trained and only five of 22 untrained amputees were still using their myoelectric prosthesis (56% and 23%, respectively). Results from an 'upper extremity function test' and a series of 'Activities of Daily Living' (ADL) tests of nine trained myoelectric prosthesis users were compared to results from one untrained user and two conventional prosthesis users. To measure the true use of the prosthesis, the authors checked battery drain and prosthesis wear; however, they mentioned that using an event counter for grip would have been more accurate. Based on the extent of use, prosthesis users were classified in three groups (regular daily users-confirmed by the battery drain and wear; regular daily users-who claim to be so, but not confirmed; and occasional users). Five out of nine who continued to use their myoelectric prosthesis stated that the initial training was useful, one found training unnecessary, and two had no opinion. The observed levels of acceptance by nine myoelectric prosthesis users were poorly correlated with their technical skills, measured by performance scores from function and ADL tests (in some cases, despite poor performance at tests, extensive prosthesis use was observed). The authors stressed that training at first application enabled proper use of a prosthesis, and special care (including a spare prosthesis) and follow up increased acceptance rates of a myoelectric prosthesis. They suggested that if a patient was not using their myoelectric prosthesis, they should be prescribed another type of prosthesis. In general, patients using myoelectric prostheses were seeking technical improvements to ensure an increased number of movements and a sensory feedback mechanism.

35. **The below-elbow myo-electric prosthesis. A comparison of the Otto Bock myo-electric prosthesis with the hook and functional hand** (Northmore-Ball MD, 1980)<sup>18</sup>

This study reports on findings from the Workmen's Compensation Board of Ontario's myoelectric program, for the period 1974-1978. In total, they fitted 59 below-elbow amputees with myoelectric hands, the highest numbers appearing in 1977 and 1978, after the introduction of the Otto-Bock six-volt system. None of the prostheses studied had a powered unit for rotating the wrist. Prosthetic use in these patients fell in to four groups:

using an electric hand, using a hook, using a cable-operated hand, or not using a prosthesis at all. After more than a year following the myoelectric prosthesis fitting, 43 amputees were interviewed (mean follow up 16 months). Four of the remaining 16 amputees had various reasons for not being interviewed but the remaining 11 merely declined to be interviewed. The purpose of the study was to assess how long the myoelectric prostheses were used in the workplace, at home, at social events, and how extensive its use was compared to that of other types of prostheses or no prosthesis. Amputees were also interviewed on their prosthesis use before being fitted with a myoelectric hand.

After fitting of a myoelectric hand, the use of a hook at work and the use of a ‘functional hand’ in non work activities were seen to decline. When not at work, myoelectric prostheses were frequently ‘switched off’ (cosmetic use). When at work, the mean number of grasps with myoelectric prostheses was much higher (functional use) when compared to non work activities. However, since the amputees were not provided with a microcounter at the beginning of the study, these numbers were approximations based on conversations with the patients. The authors concluded that there was a positive attitude from patients towards the myoelectric hand because of its appearance, function, and lack of an associated harness. Modifying factors (either positive or negative) for myoelectric hand use were job type, age at time of accident, and capability of using a cable-operated hand. Amputees using myoelectric hands were generally working at office-type jobs. The authors did not find a relationship between prosthetic use and time interval between accident and prosthetic fitting. According to interview results, the major concern for not using a myoelectric prosthesis was the ‘fear of damaging’ the device or the glove. The authors suggest that myoelectric hand research should focus more on motor function (e.g. finger control, durability), rather than sensory feedback.

36. **Clinical application study of externally powered upper-limb prosthetics systems: the VA elbow, the VA hand, and the VA/NU myoelectric hand systems** (Lewis EA, 1975)<sup>87</sup>

The Veterans Affairs Research Centre for Prosthetics conducted a study over the period of 1971-1973. Their goal was to evaluate a number of experimental external prosthetic components (VA switch-controlled elbow, VA switch-controlled hand, VA switch-controlled system, and VA/NU myoelectric hand system) as well as to educate their clinical prosthetic teams on these new emerging technologies. Eighty-four amputees working with 18 clinical teams were fitted with the new prosthetic components. The investigators chose amputees who already had experience with a conventional body-powered prosthesis with the stated intention of being able to utilize ‘before/after’ evaluations. Sixty-nine subjects of the initial 84 test subjects completed a three-month test period wearing the new components. Fifteen of the 69 amputees tested were fitted

with the VA/NU myoelectric hand, which operated by detection and amplification of the myoelectrical activity of two stump muscle groups. Signals were captured by two electrodes, amplified and transmitted to activate the motor. Hand speed was proportional to the degree of myoelectric signals produced by the muscle contraction. After termination of the study, 10 of 15 VA/NU myoelectric hand-fitted amputees chose to continue with it. Six amputees claimed that the VA/NU hand needed less effort to operate, four found the terminal device to be easier to position and control, seven found it more naturally controlled, eleven appreciated the ‘lack of harness’, and eight thought that it provided better cosmesis. The disadvantages listed by some amputees included: inadvertent operation of the device, slow speed, noisiness, limited lifting power (not strong enough), and weight. The authors concluded that myoelectric control offered better function for the amputees without any need for a harness. They suggested that the decision about prosthetic type should be made individually for each amputee, taking into account the limitations of the device. They highlighted the importance of specialized education in fitting these new prostheses and supported ‘a few centralized fabrication facilities’. They suggested that the Clinical Team should play a crucial role in prosthetic choice for a given patient.

### *Descriptive articles*

1. **Study of issues in the development of surface EMG controlled human hand** (Ryait HS, 2009)<sup>166</sup>

Ryait et al. published an article summarizing the developments in the area of myoelectric prostheses. The article consists of three parts, the first explaining EMG signal properties, the second on mathematical models to analyze EMG signals, and the third describing different artificial hand designs which use EMG signals. Citing papers from conferences of the Institute of Electrical and Electronics Engineers, they point out recent experimental advances in myoelectric prostheses. The authors conclude that for a well-designed physical device, “The ideal requirements are material for mechanical structure having mechanical strength, flexibility and weight like bone, the controller having computational capability, speed and adaptability like brain, actuator having high torque and flexibility like muscles, and the feedback elements having sensing capability like skin.” They underline that for EMG signals to be used for a multifunction prosthesis, correlation between physiological and physical factors and the EMG signal has to be drawn.

2. **The roles of predisposing characteristics, established need, and enabling resources on upper extremity prosthesis use and abandonment** (Biddiss E, 2007)<sup>167</sup>

In 2007, Biddiss and Chau published a review paper with the aim to provide a broad picture of prosthesis use and abandonment in upper limb amputees. They used the Anderson model for health service utilization to outline the roles of predisposing

characteristics, established need, and enabling resources. They collected articles via OVID (MEDLINE, CINAHL, EBM Reviews, EMBASE, and Ovid Healthstar), ISI Web of Science, PubMed, and [www.scholar.google.com](http://www.scholar.google.com) with the keywords “upper limb” and “prosthesis” or “prostheses”. They selected the first 1000 results from each database and limited the articles to ones written in English since 1980. The number of references collected was 2435. They excluded references on “experimental prostheses and technology”, “tools for outcome measurement”, “specific case studies”, and “medical subject matter” (i.e. surgical procedures, descriptions of medical conditions and treatments). Each article was rated by level of evidence and articles with level 2 or higher evidence were included in the review. Using the Anderson behavioral model they listed possible factors in health service utilization. Gender, origin of limb loss, medical conditions, hand dominance, and level of limb loss were listed under “predisposing characteristics”. Age-specific functional needs and lifestyle related needs (work/school environment, social activities, etc.) were listed under “established need”, and rehabilitation centre (info, fitting, training, follow-up), family/peer support networks, community/social networks were listed under “enabling resources”. They presented tables on these three constructs with four columns (supporting evidence, contradictory evidence, state of knowledge, and future research/goals), each listing the related articles, including the rated level of evidence. The authors pointed out that while “level of limb loss” emerged as the foremost predisposing characteristic linked with prosthesis use, the role of “origin of limb loss” or “medical conditions” was unresolved. Myoelectric devices were more suitable for high level and bilateral limb losses. Even if correlated with use of prosthesis or return to work, amputated “hand dominance” was a minor factor. In general, gender had little effect on prosthetic use/rejection/selection. However, females were increasingly choosing anthropometric devices. “Age” in maturing pediatric populations and “lifestyle” in adult populations emerged as risk factors for prosthesis abandonment. “Lifestyle” was also related with prosthesis selection, e.g. choosing multiple prostheses. However, studies revealed conflicting results on correlations between prosthetic wear and employment. More standardized and accessible information exchange was needed; the available information was not satisfactory. With “early age of initial prosthetic fitting”, prosthetic acceptance, but not functional use, increased. For myoelectric prostheses, the benefit of “early fitting” was controversial. Also, the effect of “time lapse between amputation and first prosthetic fitting” remained unresolved. The authors underlined that prosthetic assessment and fitting should be individually based and determined by lifestyle and functional needs. “Training” was clinic-specific, not customized. Routine “follow-up” emerged as a critical factor for continuing use of prostheses. However, a few studies with longer follow-up found increased myoelectric rejection over time. The effect of the role of culture and availability of prostheses on use or abandonment was not well established. Also, how prosthesis use affects overall quality of life, especially in adult populations and non-congenital amputees, was unclear. The high expense of prostheses

affected prosthesis use, especially in developing countries. The authors concluded that there was currently insufficient evidence to delineate factors related with upper limb prosthesis use and abandonment. Development of validated, standard outcome measures, and more randomized controlled studies were necessary for more conclusive research.

3. **A review of the management of upper-limb amputees** (Jones LE, 1996)<sup>30</sup>

Jones and Davidson provide us with an in-depth review paper, which covers epidemiological features of upper limb amputations, changes in surgical management, cerebral function following amputation, immediate rehabilitation after amputation, prosthetic options, suspension and harnessing systems, prosthetic training, and long-term management issues. In their ‘prosthetic options’ section, the authors emphasize that the team and the amputee should decide on the prosthesis together, taking into account factors such as: level of amputation, phantom/stump pain, viable muscle sites (for myoelectric control), patient’s life style, cosmetic requirements, social and financial situation, comorbidities, and expectations of the family and friends. The authors explain prosthesis types including passive, mechanical, and electrical terminal devices. Myoelectrical hooks are defined as having stronger grip strength, a higher speed and less weight compared to myoelectrical hands. They refer to the Millstein study (1985) when stating the positive association between return-to-work and prosthetic use, distal level of amputation, and availability of vocational services. They also refer to the Roeschlein study (1989) which relates return-to-work with successful prosthetic rehabilitation, fewer complicating factors, higher education level, and being employed at the time of amputation. In general, distal amputations lead to higher utilization of upper limb prostheses. Some studies found higher utilization with loss of dominant hand and older age. The authors point out that almost all of the studies on upper limb prosthetic use have small sample sizes (20-60) and have prosthetic usage rates between 35-81%. One broad statement that the authors agreed on was, “Acceptance or rejection of a prosthesis is a complex mixture of psychological and technical factors.”

4. **Clinical applications of myoelectrically-controlled prostheses** (Datta D, 1992)<sup>33</sup>

Datta provides the reader with an excellent review article on myoelectric prostheses. First, a general overview of upper limb prostheses is presented. This section includes the history of the development of various prostheses, suspension and socket designs, power types (body-powered/externally-powered prostheses), methods of control (manual, voluntary, myoelectric, etc.), terminal devices (passive, active), and feedback mechanisms (sensory (visual/auditory), somatosensory (tactile), and proprioceptive (position)). Then, Datta describes myoelectric prostheses in detail. A list of available devices is presented. Patient acceptance is explained with regards to four aspects: 1) comfort and fit; 2) static and dynamic appearances; 3) function, efficiency, and effort; and 4) reliability. The usefulness of myoelectric prostheses is further explained by lists of

advantages and disadvantages. Employment consequences of myoelectric prosthesis use are mentioned – there is a positive relation between prosthesis use (type/duration) and employment level. Clinical aspects such as prosthetic selection, timing (early fitting increases the rate of prosthetic usage), surgery, psychological state of the patient, and prosthetic prescription criteria are outlined. The importance of training and of an evaluation/review system is underlined. After suggestions for future research and development, the review concludes with a summary which highlights the value of a multidisciplinary team approach for successful myoelectric prosthesis application and rehabilitation of the amputee.

5. **Workers with prostheses** (Godfrey S, 1990)<sup>32</sup>

This is a descriptive paper on upper limb prostheses. The paper outlines properties of four types of terminal devices (voluntary opening split hooks, voluntary closing grip prehensile devices, myoelectric devices and aesthetic hands). It also covers factors affecting prescription, the importance of collaborative team work, and the lack of standard prosthetic prescription guidelines to respond to the unique needs of amputees. The author compares upper limb prosthetic devices with the intact human hand and ranks them according to certain characteristics, including prehension capacity, active control, control of gripping pressure, innate feedback, size, and weight. The importance of a full assessment of the amputee including general physical condition, injuries, age, occupation, type and level of amputation, and psychological factors, is emphasized. The author favours amputee involvement in the prosthesis decision and recommends that the financial capacity of the amputee and various insurance regulations differing across the country should be taken into account. The relationship between early prosthesis fitting and return-to-work is emphasized. Unilateral below-elbow amputees are considered to have the highest potential to accept prostheses. Good self-concept, limb/body condition, and family and workplace support are important factors in prosthetic acceptance. Return to work is mostly determined by the pre-injury occupation.

*Limitations in prosthetics research*

Standard outcome measures are vital to any assessment of any intervention. According to Pasquina, outcome measures in amputee care consist of three parts: mobility, function, and quality of life (QOL).<sup>55</sup> The International Classification of Functioning, Disability, and Health (ICF) Framework of WHO is also structured around three components which can be evaluated by outcome measurement tools: body function and structure, basic functional skills (activities), and participation. The ICF Framework also takes into account the dynamic, non-linear interactions between different constructs (health conditions, components of disability, and personal and environmental factors).<sup>102,168</sup>

However, evaluations of prosthetic hands have usually focused on engineering features of

the prosthesis (range of movement, strength, reliability of the system) and/or compared the advantages/disadvantages of different prosthetic types. For example, functionality of a prosthetic hand is rarely compared to the natural hand.<sup>103</sup> Prosthetic studies performed in laboratory settings reflect optimal possibilities rather than real life conditions.<sup>7</sup> Many of the published studies on myoelectric prostheses are on experimental prosthetic hands or new features developed in highly technological based settings.<sup>77,78,90-93</sup> Although, there has been an effort to develop standard outcome measures for upper limb prosthetic use in children, internationally accepted and validated measurement tools for adult patients are lacking.<sup>7,84</sup> The scarce number of standardized measurement tools and heterogenous outcome reporting in the literature restrict collaboration of study teams from different prosthetic centres and limit comparison of results from various studies.<sup>84</sup> Data collection methods on amputations vary across jurisdictions and countries as well. This limits comparison of incidence rates for epidemiological purposes.<sup>30</sup> One general concern with many survey questionnaires mailed to prosthetic users is that the ones who respond (~50%) are usually those who continue to use their prostheses, and those who do not respond are usually non-users.<sup>11</sup> Therefore, results from questionnaire surveys do not represent the opinions/preferences of all upper limb amputees who were once prescribed a prosthesis.<sup>104</sup> For Internet-based surveys, the researcher and reader can never be sure if the survey was actually completed by the amputee or not.<sup>19</sup> In comparative studies, the control systems of prostheses are frequently assessed without keeping terminal devices constant across compared groups. For example, a myoelectrically controlled prosthesis with a hand has been compared to a body-powered prosthesis with a hook.<sup>89</sup> This makes any generalizability virtually impossible.

## Coverage Policies

### *Canada*

#### BC

Currently, British Columbia Medical Services Plan, which is the provincial government health insurance plan for BC residents, does not cover prosthetic limbs. However, PharmaCare Plan of BC covers designated permanent prosthetic devices for Fair PharmaCare Plans B (residents of long-term care facilities), C (through the Ministry of Human Resources) or F (children eligible through the ‘At Home Program’ of the Ministry of Children and Family Development). Coverage depends on income level and the amount left after the deductible. When the cost of a prosthetic device is over \$400, pre-approval by PharmaCare is required. PharmaCare’s mandate is to help patients in obtaining and maintaining their basic mobility, hence, back-up prosthetics or prosthetic

limbs/accessories for sports activities are not covered. If the claim does not clearly fall within the PharmaCare coverage policy, a case-by-case decision will be made based on the patient's activity level, physical condition, and other factors. The policy allows a substantiated prosthetic replacement every three years.<sup>105,106</sup>

WorkSafeBC is the Workers' Compensation Board of British Columbia. Under section 21(1) of the Workers Compensation Act,<sup>107</sup> WorkSafeBC is responsible for the cost of health care benefits for compensable injuries and occupational diseases. This includes necessary hospitalization, treatment provided by recognized health care professionals, prescription drugs, and necessary medical appliances. Health care benefits are provided on accepted claims for compensation from the date of injury.<sup>108</sup> A worker will usually receive treatment prior to the adjudication of a claim. Claim costs are generally paid only when the claim is accepted.<sup>109</sup> Currently, WorkSafeBC looks at each individual amputee's prosthesis needs on a case by case basis and pays associated health care and hardware costs accordingly.

## Alberta

The Alberta Health Care Insurance Plan Medical Procedure List does not include artificial limbs (as of November 30, 2008); they are not covered by the provincial health plan.<sup>110</sup>

In Policy 04-06 PART II of the Workers Compensation Board (WCB) of Alberta policy manual, which addresses 'General' applications, it is stated that the Board will provide or pay for an artificial limb when a compensable injury results in the loss of a hand, foot, arm or leg. The same policy document states that a non-standard, not generally accepted medical aid or experimental medical aid may be paid for upon written submission from a treating physician that presents the case for the proposed medical aid.<sup>111</sup> Some myoelectric devices are listed in the 'Prosthetics and Orthotics Fee Guide' of the WCB of Alberta.<sup>112</sup>

## Manitoba

When prescribed by a medical practitioner, limb prosthetic services for all Manitoba residents are covered under their provincial health care plan. Prosthetic devices and services can only be provided by a practitioner certified by the Canadian Board for Certification of Prosthetists and Orthotists. Unless there is a change in prescription or damage to the device, a new prosthesis may only be claimed every two years (with no deductibles). This coverage policy is general and does not specifically mention myoelectric prostheses or any other specific type of prosthesis.<sup>113</sup>

According to The Workers Compensation Board of Manitoba policy on Medical Aid (section # 44.120.10), the WCB of Manitoba will pay for standard prostheses when “required by reason of a compensable injury” and “likely to improve function or minimize the chance of aggravating the existing injury or of causing a further injury”. The policy also states that “myoelectric prostheses may be approved if a specialist at an approved facility assesses the claimant and specifically recommends such a device”. When a myoelectric device is approved, another regular prosthesis is also authorized for back up. The Administrative Guidelines in this policy permit replacement of artificial limbs on the recommendation of a prosthetist, without a doctor’s report, and state that “the WCB will not generally place maximum limits on the cost of medically prescribed devices”.<sup>114</sup>

### New Brunswick

A limited number of residents of New Brunswick are covered for the cost of limb prostheses and maintenance/repairs under the Prosthetic Program through Family & Community Services. However, the policy clearly states that myoelectric prostheses are not covered.<sup>115</sup>

The Workplace Health, Safety and Compensation Commission of New Brunswick retains a policy regarding Prostheses, Orthoses and Assistive Devices (No. 25-007), which became effective on January 1, 2005. This policy states that the Commission will cover prostheses if they are for the treatment of a compensable injury. The Commission will determine the necessity, character, and sufficiency of medical aid and they will only approve devices that are medically effective and directly improve functioning for Return to Work (RTW) and Activities of Daily Living (ADL). In some limited cases the Commission may also provide a device which will enable participation in social or recreational activities and will indirectly support rehabilitative goals.<sup>116</sup>

### Newfoundland and Labrador

Newfoundland and Labrador Medical Care Plan lists the ‘provision of medical appliances’ under specific services which are NOT insured under the Plan.<sup>117</sup>

The Workplace Health, Safety & Compensation Commission of Newfoundland and Labrador covers assistive devices and prostheses when they are appropriate for a compensable injury of the worker.<sup>118</sup> However, the Health Care Services chapter of their policy document does not specifically mention ‘prosthetic devices’ in the Health Care Devices & Supplies section (Procedure number: 58:00).<sup>119</sup>

## Nova Scotia

The Nova Scotia Provincial Health Plan fact sheet indicates that there is “some coverage for prosthetic equipment for eligible persons. With prior approval, artificial limbs are covered once every four years.”<sup>120</sup> There is no specific mention of myoelectric upper limb prostheses.

The Workers Compensation Board of Nova Scotia provides and pays for health care benefits for injured workers. However, many benefits require approval in advance. Some specialized services and equipment required for recovery, including artificial limbs (also maintenance and repair of equipment), are covered.<sup>121,122</sup>

## Ontario

For Ontario residents with a valid Health Card, the Assistive Devices Program (ADP) of the Ministry of Health and Long-Term Care covers up to 75% of the cost of conventional upper and lower limb prostheses and powered upper limb prostheses (electric and myoelectric arm prostheses). Limbs designed for only certain activities, such as recreation, are not covered. Also, if the prosthetic device can be provided by the Workplace Safety and Insurance Board or through the coverage for Group ‘A’ veterans, it is not covered by the ADP.<sup>123-125</sup>

The Workplace Safety and Insurance Board of Ontario (WSIB)’s policy (# 17-07-05) on Prosthetic and Assistive Devices indicates that WSIB provides assistive devices and prostheses when necessary. This policy includes provision of artificial limbs with no exceptions. If repair, adjustment or replacement is needed as a result of general wear and tear, these are also covered. There is also a special section about payment for the provision, repair and/or replacement of a swim-leg, a special waterproof prosthesis.<sup>126</sup>

## Prince Edward Island (PEI)

Artificial limbs are not covered under the Medical Services Plan of PEI.<sup>127</sup> Some prosthetic services might be covered under the PEI Disability Support Program.<sup>128</sup>

The Workers Compensation Board (WCB) of PEI has a policy in place for Orthoses, Prostheses, and Assistive Devices (POL 04-20), which was last updated on October 26, 2006. To be covered by WCB, the need for the prosthesis should be the result of a compensable work injury and should be recommended by an approved health care provider. WCB will authorize payment for the full cost of prostheses if they are medically effective in the treatment or ongoing care of a compensable injury. They will

not cover prostheses that have no medical or rehabilitative value, or that exceed what the Board considers to be sufficient to restore function.<sup>129</sup>

## Quebec

Those covered by the Health Insurance Plan, who meet the program's eligibility requirements, are insured for the purchase, adjustment, replacement, and repair of orthotics and prosthetics. The policy defines the properties of a prosthetic as “a prosthetic is designed to fully or partially replace an amputated limb or a limb that is completely or partly missing and to restore its primary function or original appearance” and does not distinguish between prosthetic types for coverage.<sup>130</sup>

The Commission de la santé et de la sécurité du travail (CSST) is assigned to administrate the occupational health and safety plan of Quebec. The Act respecting industrial accidents and occupational diseases (AIAOD) includes regulations on the payment of compensation when necessary, the supply of health care, and assistance with rehabilitation.

According to section 198.1 of the Act, “The Commission shall pay the cost of the purchase, adjustment, repair and replacement of a prosthesis or orthosis referred to in paragraph 4 of section 189 as determined by regulation by the Commission, which regulation may specify the cases where, the conditions on which and up to what amount payments may be made, as well as the prior authorizations to which such payments may be subject.”

As long as they are deemed necessary by the physician in charge, “exercises to adapt to a prosthesis or an orthosis” are considered as part of physical rehabilitation.<sup>131</sup>

## Saskatchewan

The Saskatchewan Aids to Independent Living (SAIL) Program aims to assist the independence of persons with permanent physical disabilities. Services covered include provision and repair of prosthetic and orthotic appliances provided through two provincial workshops at Wascana Rehabilitation Centre (Regina) and the Saskatchewan Abilities Council (Saskatoon). Under the SAIL Program, artificial limbs and accessories are supplied, fitted, adjusted, and repaired without charge.<sup>132</sup>

The Workers' Compensation Board of Saskatchewan has a policy on Expenses – Orthotics/Appliances – Provision, Replacement and Repair (POL 17/2008), effective date January 1, 2009. The policy includes artificial limbs and states that eligibility depends on a number of factors: the need has to be a result of a compensable injury, the limb has to

be used as a functional aid during the recovery period or on a permanent basis, and it must be prescribed by an approved health care practitioner. Another policy item states that repair and replacements will be on a case by case approach.<sup>133</sup>

### Northwest Territories and Nunavut

The Northwest Territories (NWT) Health Care Plan outlines the coverage policy regarding prostheses in its Medical Supplies and Equipment section.<sup>134</sup> People who require a prosthetic device must submit a letter from their physician or occupational therapist to the Department of Health and Social Services prior to their purchase. Unless they are covered under another health care plan (such as Workers Compensation or private insurance plans), prostheses will be covered through the NWT Health Care Plan.<sup>135</sup>

The Workers' Compensation Board of the Northwest Territories and Nunavut covers medical apparatuses (including prostheses) when they are required because of a compensable injury.<sup>136</sup> For the purchase, repair or replacement of a device, the worker needs to obtain pre-approval from the Board. Repair or replacement is provided when needed as a result of reasonable (expected) wear and tear, or when the device is lost, damaged or destroyed in a work-related incident. Further details of policies can be found in policy documents '04.02 Payment for Medical Aid' and '04.08 Medical Devices', which both became effective on March 31, 2008.<sup>137</sup> Nothing specifically on myoelectric prostheses was mentioned.

### *The United States*

The Centers for Medicare and Medicaid Services (CMS) use the Healthcare Common Procedure Coding System (HCPCS) coding list. Level I codes are based on Current Procedural Terminology (CPT) codes, which show the tasks and services a health care provider may provide to a patient and subsequently bill to their insurance programs. Level II codes identify products, supplies, materials, and services which are not included in the CPT codes, such as ambulance services, prosthetics, medical equipment, and supplies (Durable Medical Equipment, Prosthetics, Orthotics, and Supplies – DMEPOS) when used outside a medical office. When HCPCS Level II codes are used for durable medical equipment, they are usually billed by medical suppliers. Myoelectric prostheses are listed in Level II codes.<sup>138</sup>

According to the Amputee Coalition of America, as of September 9, 2010, nineteen US states have some coverage for prosthetics under State Health Care Plans (Oregon, Maine, California, Indiana, Colorado, New Hampshire, Massachusetts, New Jersey, Rhode Island, Vermont, Louisiana, Arkansas, Iowa, Texas, Maryland, Virginia, Missouri, Illinois, and Utah).<sup>173</sup> For example, Bill 2517 passed by the Oregon Legislative Assembly

on April 23, 2007 reads as “All individual and group health insurance policies providing coverage for hospital, medical or surgical expenses shall include coverage for prosthetic and orthotic devices that are medically necessary to restore or maintain the ability to complete activities of daily living or essential job-related activities and that are not solely for comfort or convenience. The coverage required by this subsection includes all services and supplies medically necessary for the effective use of a prosthetic or orthotic device, including formulating its design, fabrication, material and component selection, measurements, fittings, static and dynamic alignments, and instructing the patient in the use of the device”.<sup>170</sup> Some bills passed in the above-listed states regarding prosthetic coverage require ‘prior authorization’ and limit the prosthetic devices to be the ‘most appropriate model that adequately meets the medical needs of the patient’. Some states have explicit exclusions, such as Iowa House Amendment 1054 to House File 311, which states, “Coverage is not required pursuant to this section for... myoelectric devices”.<sup>171</sup>

Some US states have posted their coverage policies for myoelectric prosthetic devices through their Medicaid Services. For example, in the New York State 2008 Medicaid Fee Schedule, myoelectric devices are covered only when they are medically necessary as determined by an approved amputee clinic.<sup>139(p144)</sup> Medicaid Program Durable Medical Equipment Procedure Codes included are: L6935, L6945, L6955, L6965, L6975, L7190, L7191, L7007, L7008, and L7009.<sup>139</sup> The Montana Medicaid current Fee Schedule for Durable Medical Equipment (January 2008) includes codes L6925, L6935, L6945, L6955, L6965, and L6975 related to myoelectronically controlled devices.<sup>140</sup>

The Amputee Coalition of America (ACA) advocated for “coverage for durable medical equipment, prosthetics, orthotics, and supplies (DMEPOS) which are critical to people with limb loss” in the Affordable Health Choices Act.<sup>141</sup> The ACA supported the Prosthetics Parity Act (introduced to the US Congress on March 13, 2008 (HR. 5615) and to the US Senate on September 18, 2008 (S. 3517)) and the Prosthetic & Custom Orthotic Act (introduced to the US Congress on May 21, 2009 (H.R. 2575)). The Affordable Health Choices Act was reported by the committee at the US Congress on July 17, 2009 (H.R. 3200)). One bill related to health care decisions for people with limb loss, the Patient Protection and Affordable Care Act (H.R. 3590), was signed by the President and took effect as of March 23, 2010.<sup>142</sup>

### VA myoelectric policy

The Prosthetics and Sensory Aids Service is that section of the US Department of Veterans Affairs (VA) which oversees prosthetic services. The VA has regional Prosthetic/Orthotic Laboratories for custom fabrication and fitting of prostheses, and also has local contracts with prosthetic and orthotic facilities to ensure easier access for patients. According to our direct correspondence with the clinical manager of the VA

Central Office (VACO), the VA does not have a specific policy regarding myoelectric prosthetic devices and who should be fitted with a myoelectric prosthesis.[Milani J. Clinical Manager, VACO. email Sep 26, 2008.] Currently, when a patient is evaluated for a myoelectric prosthesis in an Amputee Clinic, there is an interdisciplinary team assembled to assess a number of criteria:

- Does the patient have the cognitive ability to use a sophisticated device and the ability to don and duff the prosthesis correctly?
- Will the patient be able to care for the prosthesis (such as keeping electrodes clean, not immersing the prosthesis in water, charging the battery)?
- Is the residual limb free of scars at the proposed electrode sites?
- Will the patient be able to tolerate the myoelectric prosthesis as the fit is more intimate and the prosthesis is likely to be heavier than a conventional prosthesis?
- Is the patient motivated to use the myoelectric prosthesis?
- Does the patient live in a remote area where they may not be able to have the myoelectric prosthesis appropriately serviced?
- Has the patient worn a prosthesis prior to evaluation, conventional or myoelectric?
- Does the patient work, and if so, where? Is the work environment unsuitable for a myoelectric prosthesis?

### Workers' compensation system in the United States

Unfortunately, we were not able to find coverage policies specifically on myoelectric prostheses for individual Workers' Compensation Boards in the US. According to WorkersCompensation.com - The Workers' Comp Service Center, "All states basically allow for "full coverage" of workers' compensation benefits. This means there is no statutory limitation on either the cost or time for medical care. Most states allow for coverage by the private insurance industry. Six states have an exclusive fund wherein the state is the insurance carrier, and four of those also permit self-insurance."<sup>143,144</sup>

#### Washington State Department of Labor and Industries

Washington States Department of Labor and Industries handles requests for prosthesis coverage 'on a case by case basis'. They have developed a guideline document entitled 'Lower & Upper Extremity Prostheses Basics', which includes four detailed decision charts based on: amputation level, diagnosis and residual limb length, residual limb strength, and work demands. This guideline has been in use for prosthetic coverage decisions since August 25, 2009.[McCandless L. Office of the Medical Director, Washington State Department of Labor and Industries. email Feb 16, 2010.]

## Private health care insurance

### Aetna

Based on policy published in Aetna Clinical Policy Bulletin (# 0399), which was reviewed on July 27, 2010, “Aetna considers myoelectric hand prostheses medically necessary for members with traumatic or congenital absence of forearm(s) and hand(s). Aetna considers myoelectric hand prostheses experimental and investigational for all other indications.”<sup>145</sup>

### CIGNA

CIGNA covers myoelectric prosthetic devices as a medical necessity only if all of the following conditions are met: Patients must have the required cognitive ability and sufficient remaining muscle microvolt threshold to operate the myoelectric prosthesis; a standard body-powered prosthesis should not be sufficient for the patient’s functional activities during daily living. This coverage position/policy of CIGNA (# 0233) was revised on November 15, 2010 and states that in the case of conflict, a participant’s benefit plan document will supersede the information in the coverage position.<sup>146</sup>

### Empire BlueCross BlueShield

Empire BlueCross BlueShield adopted a Clinical UM Guideline (CG-DME-28) regarding myoelectric upper extremity prosthetic devices which was reviewed on February 25, 2010. According to this guideline, Empire BlueCross BlueShield considers myoelectric prosthetic devices medically necessary when all of the following criteria are met: sufficient neurological, myocutaneous, and cognitive function to operate the prosthesis; a limb loss/amputation above or at the wrist; sufficient microvolt threshold in the residual limb muscles; and no comorbidities that could interfere with prosthetic function (for example, neuromuscular disease) or unsuitable living environment. Also, it should be determined that a standard body-powered prosthesis would not be sufficient to meet the functional needs of the patient.<sup>147</sup>

### Blue Cross Blue Shield of Rhode Island

Blue Cross Blue Shield of Rhode Island’s orthotic and prosthetic services mandate is met by a policy which became effective on November 2, 2006 and was last updated on November 2, 2010. It states that “covered benefits for orthotic or prosthetic devices shall be limited to the most appropriate model that adequately meets the medical needs of the patient as determined by the insured’s treating physician”. It also states that medical necessity and benefits as described in the subscriber agreement will apply.<sup>148</sup>

### UNICARE

UniCare uses Clinical Utilization Management (UM) Guidelines for coverage decisions. The effective date of the Clinical UM Guideline on Myoelectric Upper Extremity Prosthetic Devices (CG-DME-28) is April 21, 2010.<sup>149</sup>

A myoelectric upper extremity prosthetic device is deemed medically necessary if all of the following criteria are met; otherwise, it is considered not medically necessary.

1. “The individual has sufficient neurological, myocutaneous and cognitive function to operate the prosthesis effectively; and
2. The individual has an amputation or missing limb at the wrist or above (i.e., forearm, elbow, etc.); and
3. The individual is free of comorbidities that could interfere with maintaining function of the prostheses (i.e., neuromuscular disease, etc.); and
4. The individual retains sufficient microvolt threshold in the residual limb to allow proper function of the prostheses; and
5. Standard body powered prosthetic devices cannot be used or are insufficient to meet the functional needs of the individual in performing activities of daily living; and
6. The individual does not function in an environment that would inhibit function of the prosthesis (i.e., a wet environment or a situation involving electrical discharges that would affect the prosthesis).”

### TUFTS Health Plan

According to their Medical Necessity Guidelines on Upper Limb Prostheses (ID# 2105790, Effective Date: March 16, 2009), TUFTS Health Plan covers myoelectric prosthetic devices if all of the following conditions are met: The amputation should be a minimum of a wrist or above partial limb amputation; the amputee should have sufficient neurological, myocutaneous, and cognitive function, and sufficient microvolt threshold in the residual limb to operate the prosthesis; and the living environment should be appropriate (a wet environment or situations involving electrical discharge would inhibit the function of the prosthesis). It should also be clear that a standard body-powered prosthetic device is inappropriate or insufficient for the amputee to perform activities of daily living.<sup>150</sup>

## Summary and recommendations

### – **Work injuries**

A study from Ireland on hand injuries states that over half of hand injuries occur at the workplace and the majority of them involve manually skilled workers. These injuries take longer to return-to-work compared to injuries acquired at home or during recreational activities, and are more costly.<sup>151</sup>

### – **Usually men**

Upper limb amputees are usually young men.<sup>10</sup> Dillingham reports that “Men are at higher risk than women for limb loss, especially with regard to trauma-related amputations.”<sup>35</sup> Gender differences in upper limb amputations – often trauma-related – could be explained by the nature of tasks men perform at work and during recreational activities.<sup>28</sup>

### – **Early prosthetic fitting**

Early prosthetic fitting helps amputees.<sup>30-32,37,54,88,152</sup> It may increase functionality of the prosthetic user in the future<sup>25,31</sup> and positively influence the potential to return-to-work.<sup>32,152</sup> Malone calls the first month after amputation the “golden period” for prosthetic fitting. One hundred percent of their injured-at-work study subjects who were fitted with a prosthesis within 30 days of surgery were back to work four months after their injury; whereas those fitted with a prosthesis after 30 days were back to work 6 to 24 months following injury.<sup>152</sup> The positive effect of “early prosthetic fitting” (in the first 60 days from amputation) on “frequency of prosthetic use and satisfaction with the device” emerged as the most important finding of a retrospective cohort study of 935 amputees with major limb loss. This effect was significant after controlling for various socio-demographic and amputation characteristics of the study subjects.<sup>169</sup> A follow up study after “early preparatory prosthesis application” showed that 15 of 18 amputees continued to use their prosthesis for at least eight hours/day.<sup>88</sup> Another study found that early provisional prosthetic fit would improve “acceptance and use of prosthesis” as well as “return to prior functional levels”.<sup>38</sup>

### – **Multiple prostheses**

For appropriate prosthesis selection, amputees (and families) should be given accurate information on available prosthetic types.<sup>30</sup> Supan states that “all amputees should be fitted with the type of prosthesis that fits their goals and lifestyle as soon as possible after their amputation.”<sup>83</sup> Generally, amputees will require more than one type of prosthesis and should be offered a variety to choose from.<sup>10,32</sup> A few authors state that amputees should be able to possess additional prostheses besides their principal prosthetic device to be used in different settings as required.<sup>5,9,10,16,37</sup>

### – **Level of amputation**

Prosthetic usage and acceptance rates are related with the level of amputation; distal amputees use their prostheses more.<sup>1,4,5,7,11,17,23-26,28,32,88</sup> For example, in one

retrospective study, prosthetic usage in a below-elbow amputees group was 94% and in an above-elbow amputees group was 43% (myoelectric and body-powered prostheses together). The author concluded that “below-elbow amputees will predictably use a prosthesis and should have one prescribed”.<sup>26</sup> However, some studies disagree. The Roeschlein study states that level of amputation does not differentiate prosthetic success<sup>20</sup> and the Kyberd study finds no significant correlation between the level of amputation and prosthetic usage.<sup>13</sup>

– **Which hand?**

Some studies found successful prosthetic use was related with loss of the dominant hand,<sup>4,5,7,24,26,32</sup> whereas others found no such relationship.<sup>6,13,20,22,25</sup>

– **Return-to-work**

Female and older amputees are less likely to return to work.<sup>26</sup> Amputees using prostheses have a higher chance to return to work.<sup>4,5,11,15,17,20,26,46</sup> Research by Fernandez et al. found that 51% of the upper limb amputees in the study continued working after amputation and 80% of those who did had a prosthesis.<sup>46</sup> During the interviews of the Roeschlein study, the employment rate in the ‘successful prosthesis users’ group was significantly higher than in the ‘unsuccessful prosthesis users’ group.<sup>20</sup> In Datta’s study, out of four amputees who abandoned their prosthesis, three were unemployed (75%); and out of seven amputees who were prosthesis users, only one was unemployed (14%).<sup>4</sup>

– **Prosthesis wear time**

Acceptance of a prosthetic aid by an individual is a complex issue with interacting physical, psychological, technical, and socioeconomic factors.<sup>16</sup> A few studies reported that if a prosthesis is worn, it is worn for most of the day.<sup>12,13,17,19,104</sup> Wearing a prosthesis increases the range of activities an amputee can perform.<sup>4</sup> Amputees who wear their prosthesis for longer time periods are less likely to be depressed.<sup>153</sup>

– **Multidisciplinary**

Prosthetic decision making requires the comprehensive, collective work of a multidisciplinary rehabilitation team.<sup>4</sup> According to Schultz, there is a lack of agreement in the preferences of prosthetic users and of prosthetic experts.<sup>154</sup> The surgeon, family physician, prosthetist, physiotherapist, vocational rehabilitation counselor, and psychologist should work together in partnership with the patient and the family.<sup>32</sup> The most desirable scenario would be to initiate the rehabilitation of the amputee prior to amputation.<sup>54</sup> Various authors point out the important role of a multidisciplinary clinical team in the follow up care of the patient.<sup>5,10,17,37,54</sup>

– **Adequate information**

Health care research from different areas indicates that prepared and informed patients are more likely to comply with treatment and to achieve positive health outcomes.<sup>155</sup> Patients need early information about the consequences of their

amputation, the available help they can receive from a rehabilitation centre, and the possible problems that may be encountered after rehabilitation.<sup>25,54</sup> Importantly, amputees and their families need accurate information on possible prosthetic choices.<sup>30</sup> Seventy percent of amputees who participated in the Datta study voiced concerns that they did not receive adequate information and counseling until after their attendance at the centre, which was frequently two to three months following amputation.<sup>4</sup> Herberts emphasized the value of receiving adequate information and training during prosthetic fitting.<sup>10</sup>

– **Ongoing care**

Rehabilitation programs should be ongoing with access to regular follow up, and open to potential changes in principal prosthetic type based on an amputee's ever-changing needs (for example, from active work to retirement).<sup>10</sup> Amputees utilizing a prosthesis are well advised to ensure follow up contact every two to three years for appropriate re-evaluation including education on new prosthetic technologies.<sup>104</sup>

– **Cost**

Although the benefits of prosthetic use may well outweigh its cost,<sup>17</sup> prosthetic application is part of an overall expensive rehabilitation process. Myoelectric devices cost almost six times that of a body-powered prosthesis for the same below-elbow level.<sup>32</sup> The most recent version of the myoelectric hand (the i-LIMB Hand) offers quick removal of individually powered fingers<sup>156</sup> and presently costs around \$28,000 CAD, including the battery and the charger. However, a recent case study found the functionality of this expensive myoelectric prosthesis to be not any better than a more conventional myoelectric device (DMC plus hand).<sup>164</sup>

– **Diseases/complications**

Inactivity during daily living increases the risk of developing other diseases and/or complications of existing diseases (such as diabetes, osteopenia and subsequent osteoporosis, posture/back problems, loss of another limb, or depression).<sup>157,158,172</sup> A functional prosthetic device is one important tool that may allow an amputee to pursue a physically active life style.<sup>158</sup> An appropriate prosthesis may also protect the sound limb from extra stresses associated with overuse.<sup>59</sup> All patients with amputations are well advised to pay significant attention to stump and socket hygiene and should be vigilant around weight issues as fluctuations will likely change the fit of the prosthesis.<sup>157</sup>

– **Electrically powered prosthesis**

Malone states that “there's no ‘standard’ prosthetic prescription for upper limb amputees.” He also points out that most of their study subjects “preferred externally powered components for activities of daily living and for social occasions”.<sup>152</sup> An electrically powered prosthesis was found to be the most preferred prosthetic type in a number of other studies as well.<sup>17,23,25</sup> A myoelectric prosthesis can frequently be of benefit to patients with unilateral below-elbow amputations when some key

elements are met: availability of an experienced multidisciplinary team, appropriate and timely prescription of the prosthesis, initial training at prosthetic fitting, access to technical support (including timely repairs), availability of a spare prosthesis, and ongoing follow up.<sup>10,33</sup> Stein argues that myoelectric prostheses should become an integral part of the health care system, similar to conventional prostheses, at least for below-elbow amputees.<sup>23</sup>

To date, research in the area of upper limb prosthesis supports the view that myoelectric prostheses can be a cost effective choice when use appropriately. Prescription of such a device needs to be made on an individual basis, taking into account the physical, social, psychological and vocational variables inherent in that particular patient's life. The amputee's needs/aspirations and quality of life remain important components that need to be addressed when considering such a prescription.

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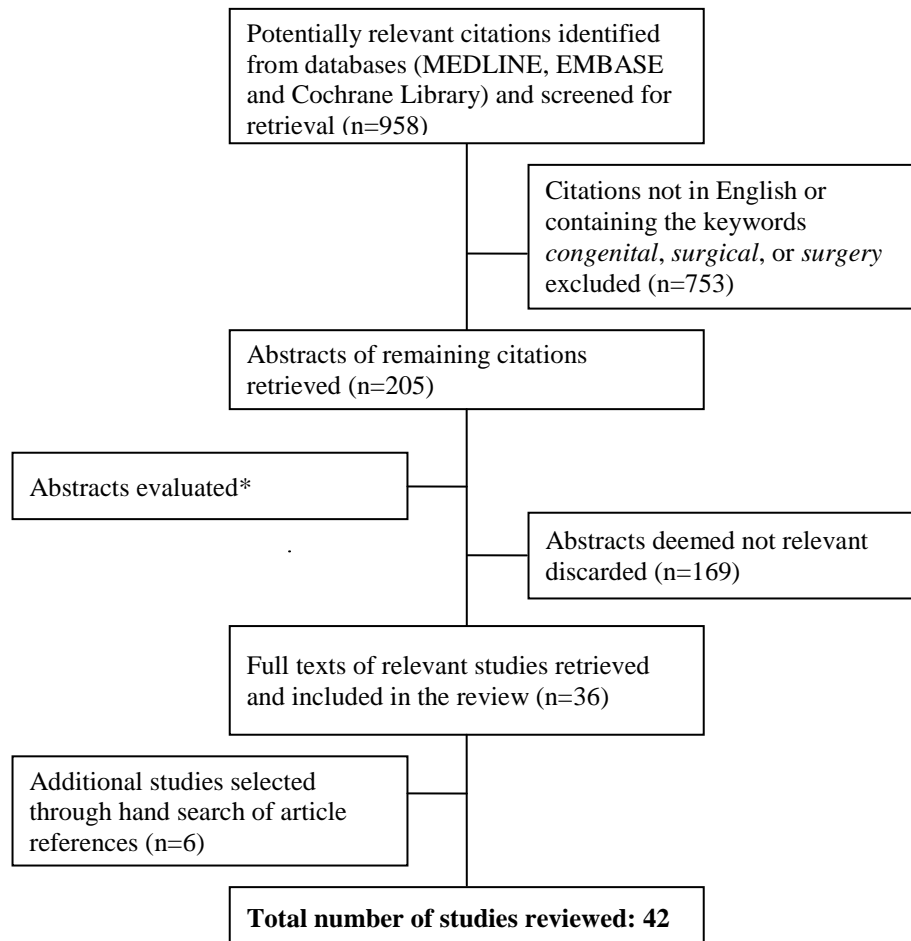
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## Appendix 1

### Flow diagram for selection of studies on upper limb myoelectric prostheses



#### \* Criteria applied during abstract evaluation

##### Inclusion

- Clinical studies with myoelectric prostheses, comparative studies of various hand prostheses, and reviews on historical development of hand prostheses (particularly on myoelectric prostheses) were included.

##### Exclusion

- Studies conducted on below-elbow adult amputees were included; studies on above-elbow amputations and partial hand amputations (finger replacements, etc.) were excluded.
- Studies conducted exclusively on children amputees were excluded.
- Studies on prosthetic applications following traumatic events were included; studies exclusively on vascular disease or cancer amputees were excluded.
- Articles focusing solely on 'measurement tools' (questionnaires, scales, etc.) or 'experimental artificial hands' (case or simulation reports from technological settings) were excluded.
- Studies on conventional body-powered prostheses were excluded unless they reported on vocational outcomes.

## Appendix 2

### WorkSafeBC Evidence-Based Practice Group levels of evidence (adapted from 1,2,3,4)

<b>1</b>	Evidence from at least 1 properly randomized controlled trial (RCT) or systematic review of RCTs.
<b>2</b>	Evidence from well-designed controlled trials without randomization or systematic reviews of observational studies.
<b>3</b>	Evidence from well-designed cohort or case-control analytic studies, preferably from more than 1 centre or research group.
<b>4</b>	Evidence from comparisons between times or places with or without the intervention. Dramatic results in uncontrolled experiments could also be included here.
<b>5</b>	Opinions of respected authorities, based on clinical experience, descriptive studies or reports of expert committees.

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## Appendix 3 Summary table of included studies

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
<b>Berke GM, 2010</b>  <b>EBPG Level of Evidence: 4</b>	Evaluating some experimental external prosthetic components and educating the clinical prosthesis teams on these emerging upper limb prosthetic components	Questionnaire 'Survey for Prosthetic Use' (conducted during 2007-2008)	Vietnam and OIF/OEF service members and veterans (US), who undertook the 'Survey for Prosthetic Use' were studied by a mixed group of American prosthetic researchers (from VA, prosthetic and orthotic clinics, university or private clinicians)	<ul style="list-style-type: none"> <li>- 581 subjects: 298 from Vietnam conflict, 283 from OIF/OEF conflict</li> <li>- Overall, over 70% Caucasian</li> <li>- Average age: 61 years (Vietnam amputees), 29 years (OIF/OEF amputees)</li> <li>- Full or part-time employment 79% (Vietnam), 54% (OIF/OEF)</li> <li>- 23% of OIF/OEF amputees were students</li> </ul>			<ul style="list-style-type: none"> <li>- All OIF/OEF servicemembers with major limb loss and all Vietnam veterans with unilateral upper-limb and multiple limb losses, and a selected group with unilateral lower limb loss were invited (total 581)</li> <li>- After excluding 100 (who abandoned or never used their prostheses, who use wheelchairs, or who had incomplete 'satisfaction data'), 230 Vietnam and 251 OIF/OEF amputees were analyzed</li> </ul>	<ul style="list-style-type: none"> <li>- Cumulative prosthetic satisfaction score was 7.0 for Vietnam and 7.5 for OIF/OEF participants</li> <li>- For unilateral upper &amp; lower limb loss, satisfaction higher with private-contract than with VA care</li> <li>- Amputees with transradial level loss more satisfied compared to ones with transhumeral level loss</li> <li>- Overall satisfaction did not significantly differ with levels of amputation for lower limb amputees</li> <li>- Less than half of the participants indicated that they received sufficient info on new types of prostheses</li> <li>- Vietnam amputees with private care were less willing to 'change their prosthesis to another one' compared to Vietnam amputees receiving VA care (<math>p&lt;0.05</math>)</li> <li>- 90% upper limb, 94% unilateral lower limb, and 95% multiple limb amputees cope with their prostheses</li> <li>- 90% were able to get repairs; and 67-85% were able to get replacements when needed</li> <li>- Factors correlated with less prosthetic satisfaction: poor socket fit, lack of involvement in prosthetic choice, difficulty with repairs/replacements, desire to change to another prosthesis (<math>p&lt;0.001</math> for all); lack of satisfaction with training (<math>p&lt;0.01</math>), skin problems (<math>p&lt;0.05</math>)</li> <li>- Findings did not change when age (for both Vietnam &amp; OIF/OEF) &amp; sex (for OIF/OEF) were controlled for</li> </ul>
<b>Blough DK, 2010</b>  <b>EBPG Level of Evidence: 4</b>	<ul style="list-style-type: none"> <li>- Estimating the cost of prosthetic devices based on Medicare 2005 costs</li> <li>- Projecting future prosthetic costs (for 5, 10, 20 years and for life-time) based on prosthesis use patterns as determined by the 'Survey for Prosthetic Use'</li> </ul>	Cost projection study using Markov Models & prosthesis use pattern data from 'Survey for Prosthetic Use'	Questionnaire responses of Vietnam and OIF/OEF service members and veterans (US), who undertook the 'Survey for Prosthetic Use' were studied	<ul style="list-style-type: none"> <li>- 581 subjects: 298 from Vietnam conflict, 283 from OIF/OEF conflict</li> </ul>			<ul style="list-style-type: none"> <li>- Medicare 2005 DMEPOS for noninstitutional providers was used as the cost reference</li> <li>- A cost matrix was developed to determine the average cost of a prosthetic device system (based on type of prosthetic device, level of limb loss and functional capacity)</li> <li>- A cost file &amp; eight Markov's Models (four for each of the Vietnam &amp; OIF/OEF cohorts) were developed based on four types of limb loss (unilateral lower, unilateral upper, bilateral upper &amp; multiple limb loss)</li> <li>- For lower limb loss: <ul style="list-style-type: none"> <li>- prosthetic device types were grouped into six: microprocessor, hybrid, mechanical, sports/specialty,</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>- Overall, significant difference in prosthetic device use between the two limb-loss cohorts (78% of Vietnam group vs. 90% of OIF/OEF group)</li> <li>- In the unilateral upper limb-loss group, 76% of the OIF/OEF group used prostheses (46% myoelectric and 38% mechanical)</li> <li>- The average 5-year projected cost for upper limb prostheses in the OIF/OEF group was higher than the Vietnam group (\$117,440 and \$31,129, respectively)</li> <li>- Authors concluded that U.S. Department of Veterans Affairs and other healthcare provider systems should be prepared for increasing costs with the emerging high technology devices (e.g. DARPA Arm) which will likely require extra training of the prosthetists, and resources to support the device use and repair</li> </ul>

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
							<p>waterproof, and cosmetic</p> <ul style="list-style-type: none"> <li>- They focused on two levels (transbital or transfemoral), which made up 87% of all lower limb losses</li> <li>- Medicare Functional Classification Level (MFCL) was used to assign functional level</li> <li>- For upper limb loss: <ul style="list-style-type: none"> <li>- there was no equivalent of MFCL to determine functional level</li> <li>- prosthetic device types used: myoelectric, hybrid, mechanical &amp; cosmetic</li> <li>- focused on two most common levels (transradial or transhumeral), which made up 71% of all upper limb losses</li> <li>- costs of the remaining five levels were derived based on expert opinion</li> </ul> </li> </ul>	
<p><b>McFarland LV, 2010</b></p> <p><b>EBPG Level of Evidence: 4</b></p>	Describing prosthetic-device use patterns in two large groups of servicemembers and veterans with combat-associated upper-limb loss	Questionnaire 'Survey for Prosthetic Use' (conducted during 2007-2008) (cross-sectional study)	Vietnam and OIF/OEF service members and veterans (US), who undertook the survey were studied by a group of researchers	<ul style="list-style-type: none"> <li>- Total # of survey participants: 581</li> <li>- Study subjects with combat-associated major (digit-only loss excluded), unilateral upper limb loss: 47 (from Vietnam conflict), 50 (from OIF/OEF conflict)</li> <li>- Mean age: 60 (Vietnam veterans) and 30 (OIF/OEF veterans and servicemembers)</li> </ul>	Response rate for participants from Vietnam conflict: 65%; for participants from OIF/OEF conflicts: 59%		<ul style="list-style-type: none"> <li>- Survey measures were broad: demographics, military status, employment, comorbidities, injury impact rank, prosthetic type (myoelectric/hybrid, mechanical/ body-powered, cosmetic), satisfaction with the prosthesis</li> <li>- Rash analysis used to assess upper-limb function</li> <li>- Chi-square, Student's t, Fisher exact, Mann-Whitney U-tests used for statistical analysis as appropriate</li> <li>- Forward stepwise technique was used for multiple linear regression</li> </ul>	<ul style="list-style-type: none"> <li>- 70% of Vietnam group and 76% of OIF/OEF group were using an upper-limb prosthesis</li> <li>- Vietnam group used mechanical/body-powered prostheses more (78%) &amp; OIF/OEF group used myoelectric/hybrid prostheses more (46%)</li> <li>- ADL was associated with level of limb loss, increasing with more distal losses</li> <li>- Prosthesis rejection or dissatisfaction was associated with type of prosthesis &amp; with level of limb loss</li> <li>- Use of 'mechanical/body-powered prosthetic devices' was associated with higher upper-limb activity (for both Vietnam and OIF/OEF groups)</li> <li>- Transhumeral-level limb loss was associated with lower upper-limb activity (for both Vietnam and OIF/OEF groups)</li> <li>- Generalizability was limited, as study population included only combat-injury-related limb-loss</li> </ul>
<p><b>Van der Niet Otr, 2010</b></p> <p><b>EBPG Level of Evidence: 4</b></p>	Determining whether i-LIMB hand (a multi-joint myoelectric prosthetic hand) had more functionality than Dynamic Mode Control Hand (DMC plus hand), a more conventional myoelectric hand with only a single joint between the thumb and two fingers	Case study	University of Groningen, The Netherlands	45-year old male with wrist disarticulation (acquired as a result of work injury in 2006)			<ul style="list-style-type: none"> <li>- Testing covered all functional levels of the International Classification of Functioning and Health (ICF) framework.</li> <li>- First the DMC plus hand was tested and 4 weeks later the i-LIMB hand was tested</li> <li>- grip and pinch strength</li> <li>- Southampton Hand Assessment Procedure (SHAP)</li> </ul>	<ul style="list-style-type: none"> <li>- The i-LIMB scores on functionality (measured by grip and pinch strength &amp; SHAP outcomes) were either lower or the same as DMC</li> <li>- The patient was more satisfied with the i-LIMB (based on TAPES)</li> <li>- VAS scores favoured i-LIMB for reliability in holding objects &amp; DMC for its strength and robustness</li> <li>- Authors concluded that: <ul style="list-style-type: none"> <li>- the patient should be given the option to choose one or the other based on their needs</li> </ul> </li> </ul>

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
							- Trinity Amputation and Prosthesis Experience Scales (TAPES) - Visual analogue scale (VAS)	- the i-LIMB's limitations should be taken into account for future research in this area
<b>Biddis EA, 2008</b>  <b>EBPG Level of Evidence: 4</b>	Developing a model for prediction of upper limb prosthesis use or rejection	Online survey	Questionnaire distributed internationally to individuals with upper limb absence through community-based support groups and rehabilitation hospitals	59 prosthetic rejecters and 132 prosthetic wearers (on average, 11± 5 hours prosthetic wear per workday)	Excluded: - Incomplete or inconsistent data (7); - Ineligible limb absence (5); - Age under 12 (9); - Data similarity and /or duplicate IP address (3); - Never been prescribed a prosthesis (34); - Infrequent wearers (i.e., who wore a prosthesis more than once a year, but less than weekly) (17)		- Data collected on 36 variables, pertaining to individual characteristics, established need, enabling resources, healthcare utilization.  - Data analyzed in 5 stages: - basic univariate analysis - multivariate modeling - logistic regression - decision trees - radial basis function networks  - Logistic regression model performed better	- Factors like age, level of amputation, etc. (pertaining to individual characteristics and established need) were associated with prosthetic use - 'Fitting timeframe' and 'degree of involvement in the choice of prosthesis' were two main factors associated with prosthetic wear in terms of healthcare and enabling resources - People who had prosthetic fitting within 2 years for congenital and within 6 months for acquired amputations were 16 times more likely to continue using their prosthesis - Involvement of the amputee in the selection of prosthesis increased the likelihood of prosthetic acceptance 8 times - Three factors which were strongly correlated (p<0.01) with prosthesis acceptance (satisfaction with healthcare, satisfaction with prostheses, high perceived need for prostheses) were not suitable for a priori prediction for prosthetic use in this study setup
<b>Biddis EA, 2007</b> <b>Upper limb prosthesis use and abandonment</b>  <b>EBPG Level of Evidence: 2 (Appendix 2)</b>	Reviewing rejection rates, factors related with abandonment, patterns of wear, function, and consumer satisfaction with upper limb prosthesis	Systematic Review	- ~200 articles were reviewed (MEDLINE, CINAHL, EBM Reviews, EMBASE and Ovid Healthstar) - 40 included (had prosthesis rejection rates)				- Studies classified in three groups based on availability of prostheses and uniformity of experimental conditions (exclusive, uncontrolled, controlled) - Analyzed the differences between subgroups (passive prosthesis, body-powered prosthesis, electric prosthesis, no-prosthesis) using Chi-square test (with Yates' correction)	- Included studies of adult populations did not reveal higher acceptance of electric prosthesis compared to body-powered prosthesis - Study samples were heterogeneous - Studies were different methodologically - Suggestions for future studies: - multicentre studies & use of standard study tools (for generalizability) - controlled study designs (comparability of results) - use of formal statistical methods enabling meta-analysis & evaluation of statistical & clinical validity - multi-factor analysis addressing different aspects of prosthesis use/acceptance (personal, contextual & technological) & also uncovering related main & interaction effects - development/adoption of standardized measurement tools, complete/descriptive documentation of data and capture of consumer views
<b>Biddis E, 2007</b> <b>Upper-limb prosthetics</b>	Examining predisposing characteristics, established need, and available resources in a sample of	Online survey	Survey posted on health care services & community-	242 out of 266 respondents were included - average age: 43	survey completion rate: 40%	10 months	Chi square test (with Yates correction), Student's t-test, Mann-Whitney U test (or Kruskal Wallis test) and ANOVA were used for the analysis	- 'Level of limb loss' most important predisposing factor for prosthesis acceptance - In the acquired limb loss group, prosthesis rejection rate was 16% for transradial & 39% for high level amputees

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
<b>EBPG Level of Evidence: 4</b>	prosthesis users in the context of device abandonment		based support group websites for 10 months  Extensive filter techniques were used to identify false respondents	years - 51% male - 54% transradial amputation - 14% never worn prosthesis - prevalence of electric hands and body-powered hooks were similar				<ul style="list-style-type: none"> <li>- In the acquired limb loss group females had higher rejection rates</li> <li>- People in the 4-10, 24-35, and &gt;65 age groups had higher rejection rates</li> <li>- No differences in employment rate for people who use their prosthesis &amp; those who reject</li> <li>- People who reject prosthesis were less satisfied with all aspects of the prosthesis (appearance, comfort, ease of control, reliability, cost)</li> <li>- 'Established need' &amp; 'available prosthesis technology' were the most important factors in use or rejection of prosthesis</li> <li>- Dominant hand loss was not related with rejection</li> <li>- 'Perceived need for prosthesis' was important</li> <li>- Unavailability of health care team support &amp; lack of information provision was related with rejection</li> </ul>
<b>Kyberd PJ, 2007</b>  <b>EBPG Level of Evidence: 4</b>	Surveying/recording demographic & prosthetic (type & usage) data from unilateral upper extremity prosthesis users from three centres in two countries (Sweden and the UK) to assess users' preferences/satisfaction (with comparisons between countries and prosthesis types)	Postal questionnaire survey	Patients from 3 fitting centres (Edinburg, Goteborg, Stockholm)	- 156 unilateral upper extremity prosthesis users were contacted - 28% had more than one prosthesis	- Response rate 75% (117 out of 156) - 4 were excluded (did not use a prosthesis) - 113 were analyzed		- 113 questionnaires were analyzed - Satisfaction was rated using 17 variables of comfort, functionality, and daily usage (10-point scale) - Results were categorized by type of prosthesis	<ul style="list-style-type: none"> <li>- 60% mostly used cosmetic, 27% mostly used electric and 13% mostly used other type of prosthesis</li> <li>- Most amputees (76%) wore prosthesis &gt; 8 hours/day</li> <li>- Electric prostheses are an alternative for mid-radius or below amputees</li> <li>- Satisfaction/dissatisfaction mean ratings were not different in electric &amp; cosmetic prosthesis user groups</li> <li>- For electric hand users 'function', and for cosmetic hand users 'appearance' were considered most important</li> <li>- Results are not generalizable (centres do not represent the characteristics of the general amputee populations of Sweden and the UK)</li> </ul>
<b>Pylatiuk C, 2007</b>  <b>EBPG Level of Evidence: 4</b>	Studying consumer concerns of German-speaking upper limb amputees who are myoelectric hand users (via an anonymous online survey)	Online survey	Survey available through a hand prosthesis Internet homepage for 4 years (2002-2006)	- German-speaking upper limb amputees, surveyed via online questionnaire - 54 study subjects (who completed at least 50% of the questionnaire questions)		Survey available online for 4 years (2002-2006)	- Mann-Whitney U test - Answers analyzed in three groups: male, female; child	<ul style="list-style-type: none"> <li>- 55% of respondents rated the prosthesis as 'a little too heavy'</li> <li>- Grasping speed of the prosthesis was rated 'too slow' in all three groups (i.e. 76% of males)</li> <li>- At least one quarter of all three groups rated the sound of the prosthesis 'distractive'</li> <li>- With regard to cosmetic appearance, children were more content compared to the other two groups</li> <li>- Force and temperature feedback, as well as independent thumb, index, and wrist movements were additional features expected</li> <li>- If used, a prosthetic hand is usually worn more than 8 hours a day</li> <li>- Study limitation: anonymous survey (no certainty about the actual respondents)</li> </ul>
<b>Kyberd PJ, 1998</b>	Identifying problems related with different prostheses	Postal questionnaire	Amputees of Oxford Limb-	- 80 upper limb amputees of Oxford	- 56 of 80 (69%) responded		- A four-page questionnaire was designed	<ul style="list-style-type: none"> <li>- 89% wore their prosthesis 'daily'</li> <li>- If a prosthesis was worn it was worn for most of the day</li> </ul>

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
<b>EBPG Level of Evidence: 4</b>	being used by upper limb amputees still in contact with the Oxford Limb-Fitting Centre	survey	Fitting Centre located in Headington, Oxford, UK	Limb-Fitting Centre, with contact in the last 26 months - 56 respondents, out of whom: - 78% traumatic amputees - 46% below-elbow amputees - 60% body-powered - 4% myoelectric			- Effect of prosthesis weight, precision and strength (power) on user preference was questioned	- The mean prosthetic use time was 13.4 hours/day - Usage time did not correlate with type of prosthesis, level of amputation, or with the number of prosthetic problems stated - 73% percent wore their prosthesis at work - 60% mentioned problems with function (mechanical limitations, grip, range, etc.); 18% of these users were wearing cosmetic prostheses - Both appearance & function were essential - Being able to drive was important - Lightness (weight), long periods of operation (more than 12 hours), easily charged batteries, easy to clean gloves, & improved function are important for future prosthetic designs
<b>Gainé WJ, 1997</b>  <b>EBPG Level of Evidence: 4</b>	Assessing acceptance of limb loss and success of prosthetic use in traumatic upper limb amputees in comparison with congenital amputees	Retrospective survey	Upper Prosthetic Clinic of the Southern General Hospital, Glasgow	- 55 amputees - 23 traumatic (mean age 37) - 32 congenital (mean age 13)		In traumatic group - average age of amputation: 28 yrs - average duration of follow up: 9.6 yrs	- Methods included questionnaire, telephone or clinic review, case note review - The authors developed a scoring system for overall 'prosthetic success', which consisted of points for 'patient satisfaction', 'daily wear', and 'functional level' - Not much information provided about the statistical analysis (Student's t-test used at some point)	- Overall prosthetic success of traumatic amputees was poorer than that of congenital amputees - For traumatic amputees: - Fitting before 12 weeks after amputation yielded higher prosthetic success & higher return to gainful employment - Loss of dominant hand did not have a significant effect on prosthetic success - Myoelectric & cosmetic prostheses were favoured for social outings - Myoelectric hand was preferred for light manual tasks & office work, whereas body-powered cable-assisted prosthesis was preferred for heavier jobs & farm work
<b>Hacking HGA, 1997</b>  <b>EBPG Level of Evidence: 4</b>	Evaluating factors which had an effect on Dutch amputees in terms of prosthetic use	Postal questionnaire survey	Rehabilitation centre in Utrecht, Netherlands  (Jan 1, 1983 to Dec 31, 1992)	- 48 in total attended the Centre (3 died, 6 were not located) - 39 questionnaires sent - 29 responses  (Amputees with first application between Jan 1, 1983 & Dec 31, 1992)	Response rate 74%		- Postal questionnaire on: - patient factors (date, cause & level of amputation, age, sex, pain, hand dominance, etc.) - prosthesis factors (type, time since fitting, usage, cosmesis) - environmental factors (training, educational level, employment status, etc.) - Analyzed in three groups based on 'prosthesis wearing time' - not wearing at all, - wearing < 4 hours/day - wearing > 4 hours/day	- Below-elbow amputees wore their prosthesis longer hours compared to higher level amputees (76% vs. 50% respectively, > 4 hour/day wear) - Loss of dominant hand led to longer wearing times compared to non-dominant hand loss (89% and 40% respectively, > 4 hour/day wear) - 72% of body-powered prostheses & 78% of myoelectric prostheses were worn >4 hours/day; this was true for only 54% for cosmetic prostheses - The authors did not find any effect of employment status on prosthesis wearing time- Of 17 amputees who believed that their prosthesis fitting time was timely, 14 used their prosthesis regularly (82%); in the group who believed their initial fitting was late, the prosthesis usage rate was 25% - In this study the prosthesis rejection rate was 21%
<b>Kyberd PJ, 1997</b>	Providing retrospective data of upper limb amputees (from Oxford Limb Fitting	Retrospective review	Oxford Limb Fitting Centre, UK	- 334 upper limb amputees (another 7 were untraceable)			- Retrospectively studied age, gender, cause/level of loss, type of prosthetic, & estimated level of usage of 334	- Analysis revealed a small increase in prosthesis use by age - If only 'active' study population was considered, the

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
<b>EBPG Level of Evidence: 4</b>	Centre) to be analyzed and help future planning of upper limb provision in the UK		(Feb 1992)				upper limb amputees from computer database of the Centre - 'Active' study population were amputees who contacted the centre in the previous 2 years - Data was analyzed in 3 groups based on the principal prosthesis: cosmetic hand, working hand/hook, or myoelectric hand	percentage of people who use working devices was higher (52%) compared to cosmetic devices (37%) - The authors concluded that the most frequent prosthetic user group to attend their Centre is men with right-side, trans-radial amputations due to trauma-related injuries
<b>Atkins DJ, 1996</b>  <b>EBPG Level of Evidence: 4</b>	Establishing a national database of upper limb loss (both adults & children) & evaluating use of prostheses, trends in technology, & preferences of prosthetic users	Postal questionnaire survey	Contact info of amputees obtained from 104 entities in US (physicians, rehab facilities, the Veteran's Administration, hospitals, prosthetic manufacturers, etc.)	1575 responded to the longer survey (3 different versions): - 1020 body-powered prosthesis users - 438 electric prosthesis users - 117 bilateral prosthesis users - Older users in body-powered group (mean age 32.1 years vs. 24.9 years for electric users) - More adults in the electric prosthesis group (61% vs. 18%) - Transradial was most common amputation level (body-powered 48% & electric 53%)	Response rate 64% (out of 2477 respondents of the first one-page survey)		- Three different versions of the long survey were designed (for body-powered, electric and bilateral prostheses users) - Each survey was analyzed separately  Surveys collected info on: - gender - age - level of amputation - etiology - side involvement (unilateral/bilateral) - type of prostheses - components used - therapy & rehab experiences - funding, maintenance, and repairs - functional abilities - preferred prosthetic enhancements	- Transradial electric prosthesis users desired improvements in - bending fingers - thumb movement - visual attention - Short-term priorities: improved gloves & batteries/charging units, and more reliable electrodes - Long-term priorities: greater range of finger movements, reduced visual attention, and improved wrist movement - Recommendations for future prosthetics research: - data from different age groups (child, teenager, adult, senior) should be analyzed separately - for each functional task 'an activity analysis' should be done (properties of grasp & prehension) and should be evaluated with each prosthetic type - qualitative data obtained from written commentaries should also be obtained & analyzed - information collected (including direct access to parts of the data set) should be shared with medical professionals, patients and families
<b>Jones LE, 1995</b>  <b>EBPG Level of Evidence: 4</b>	Assessing long term rehabilitation outcome (prosthetic use and functional capacity) of all adult upper extremity amputees treated at the Rehabilitation Centre of the Royal South Sydney Hospital, Australia from 1981-1990	Survey questionnaire (by mail or in person)	Royal South Sydney Hospital, Australia  (1981-1990)	- 41 major upper limb amputees (older than 16) treated at the centre between 1981 and 1990 - 37 were contacted (4 deaths out of 41) - 27 responded - all 27 were prescribed prostheses (body-powered or cosmetic) - Mean age at amputation: 36 years	- Response rate: 73% (27 of 37)			- 10 non-respondents were younger than mean age at time of amputation- All 27 amputees were prescribed prostheses - At the time of the survey, 37% out of 27 amputees were regular prosthesis users, 19% were occasional prosthesis users & 45% were non-users - The number of people retired & unemployed doubled between the time of amputation and the survey - All unemployed people were non-users - Prosthesis usage was related with the level of amputation (distal amputees had higher usage rates) - Regular prosthetic use was essential for some jobs (such as tradesman or farmer) - After amputation the type of jobs changed to more clerical jobs from manual jobs
<b>Wright TW, 1995</b>	Evaluating patterns of prosthetic use in a sample of	Retrospective chart review	Mayo Clinic, Department of	- 330 upper extremity amputees sent short	Response rate: 46%	Average follow up: 12 years	- 330 were sent short questionnaire - 150 responded & 135 were major	- No correlation between prosthesis fitting time (greater or less than 1 year after amputation) & prosthesis use

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
<b>EBPG Level of Evidence: 4</b>	upper limb amputees with major amputations who attended the Mayo Clinic between 1975 and 1987	and questionnaire survey	Orthopedics, MN, US (1975 to 1987)	questionnaire - 150 responded - 135 met the inclusion criteria (had major upper limb amputations) - Mean age: 36 years - Trauma related: 72% - Below-elbow: 44% - Fitted with a prosthesis: 84%			upper limb amputees	<ul style="list-style-type: none"> <li>- No correlation between age at amputation &amp; prosthesis use</li> <li>- Prosthesis rejection rate was 38%</li> <li>- Reasons given for rejection were various technical &amp; functional limitations of the prosthesis; for example, less shoulder motion range was significantly related with prosthetic rejection (<math>p &lt; 0.05</math>)</li> <li>- Below-elbow amputees' prosthetic usage rate was highest (94%)</li> <li>- 100% of the bilateral amputees used their prosthesis.</li> <li>- Loss of dominant limb was significantly related with increased usage</li> <li>- Employment rate after amputation was 78%</li> <li>- Female sex &amp; stump pain were factors negatively related with employment</li> <li>- Overall prosthetic acceptance rate was 62% &amp; was 100% for 5 below-elbow amputees with myoelectric prostheses</li> <li>- Below-elbow amputees are likely to use their prostheses regularly &amp; should be prescribed one</li> </ul>
<b>Pinzur MS, 1994</b>  <b>EBPG Level of Evidence: 4</b>	Evaluating prosthetic use & functional rehabilitation of 19 consecutive traumatic upper limb amputees who attended a Level I Trauma Centre over a 9-year period	Retrospective review	Level I Trauma Centre in Maywood, Illinois, USA	19 consecutive traumatic amputees over a 9-year period  - 10 transradial - 6 transhumeral - 3 shoulder disarticulation  - At amputation 18 out of 19 amputees were employed	Except for one shoulder disarticulation, all amputees were fitted with prostheses (total fitted: 18)	Follow up examination was on average 52 months after the prosthetic fitting	<ul style="list-style-type: none"> <li>- 18 consecutive traumatic amputees over a 9-year period</li> <li>- were reexamined</li> <li>- were reviewed retrospectively</li> <li>- Preparatory functional limb used was a body-powered cable-driven prosthesis</li> </ul>	<ul style="list-style-type: none"> <li>- Functional outcome with preparatory prosthesis was excellent, especially for transradial amputees, &amp; they were fitted with a myoelectric prosthesis sooner</li> <li>- 17 out of 18 amputees initially fitted with prostheses became proficient users</li> <li>- After amputation, 4 of 18 previously employed became unemployed (only 1 transradial amputee)</li> <li>- 9 of 10 transradial amputees used their prosthesis for functional prehension</li> <li>- A high percentage of traumatic amputees could use their prostheses functionally &amp; could return to work &amp; activity level they had before amputation; pain is not a big barrier for successful rehabilitation</li> </ul>
<b>Kejlaa GH, 1993</b>  <b>EBPG Level of Evidence: 4</b>	Evaluating concerns of prosthesis users and their effects on prosthetic cessations; estimating functional levels in prosthetic users & non-users.	Questionnaire survey (in person interviews)	All amputees registered in county of Funen, in Denmark, in the period of January 1900 to December 31, 1987	- 105 upper limb amputees recorded (of whom 32 were dead and 7 did not participate) - 66 included (mean age at amputation: 24.5 years & during study: 45.1 years) - 65% of 66 had trauma-related amputation - 15% of 66 had			<ul style="list-style-type: none"> <li>- Two type of questionnaires used: one for people younger than 18, and one for people older than 18</li> <li>- Based on prosthesis usage (&gt;8 hours/day, &lt;8 hours/day, only passive prosthesis use, no prosthesis use), amputees were categorized into four groups (active, partially active, passive and non-users).</li> <li>- 7 out of 32 active prosthetic users were using myoelectric prostheses</li> </ul>	<ul style="list-style-type: none"> <li>- Active and partially active users were more often younger amputees</li> <li>- 7 of 32 active prosthetic users were employed at office work or were students</li> <li>- Heavy workers preferred conventional mechanical prostheses (mostly hook)</li> <li>- Amputees with myoelectric hands mostly complained that the prosthesis was hot, heavy, and the glove got dirty easily</li> <li>- Active prosthesis users had significantly fewer task problems than the passive and non-users</li> <li>- Myoelectric prostheses were preferred for their cosmetics and when working in clean and light work</li> </ul>

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				congenital deformities - 77% of 66 were trans-radial amputees				environments - The time lapse between amputation and initial prosthesis fitting should not exceed 6 months
<b>Silcox DH, 1993</b>  <b>EBPG Level of Evidence: 4</b>	Examining acceptance and usage of myoelectric prostheses (or alternate prostheses) & associated demographic factors	Long-term follow up study with a standard questionnaire	Emory University affiliated hospitals, Atlanta	- 44 subjects (mean age at fitting: 38 years) - 91% trauma related - 68% were distal to elbow - inclusion criterion: more than 2 years of myoelectric prosthesis usage - 40 of them owned a conventional prosthesis & 9 owned a cosmetic prosthesis as well	- 61 were fitted with a myoelectric prosthesis (Jan 1979 to Dec 1989) - 2 did not meet inclusion criterion - 1 died - 14 lost to follow up	- Average duration of follow up: 5 years	- Standardized questionnaire (on prosthetic usage patterns, reasons for rejection, training received for prosthetic use, amputee's perception of sensory feedback) - Amputees were asked to quantify the time they spent wearing their various prostheses at home, at work and for social activities; 0 to 4 points assigned based on their usage time ('no usage' to 76-100% usage, respectively) - Chi-square test with Yates' continuity correction, Spearman's rank correlation test, regression analysis, or ANOVA (alpha = 0.05)	- Negative correlation between the usage of myoelectric prosthesis & conventional prosthesis ( $r_s = -0.44$ , $p \leq 0.004$ ) - No association between myoelectric prosthesis acceptance & training from an occupational therapist - No significant association between acceptance of myoelectric prosthesis & the length of previous experience with a conventional prosthesis - No correlation between the age/sex of the amputee, the reason for amputation, the length of time before the prosthesis fitting, and the prosthesis type preferred - A relationship (not significant) between occupation type & usage exits; white-collar workers used myoelectric prostheses more than blue-collar workers - Disadvantages of myoelectric prosthesis: heavy weight, slowness, and low durability - Advantage of myoelectric prosthesis: cosmetic appearance - Rejection rate for myoelectric prosthesis was 50%
<b>Bergman K, 1992</b>  <b>EBPG Level of Evidence: 3</b>	Comparing an adaptive myoelectric hand with a conventional non-adaptive myoelectric hand in terms of prosthetic function & amputee preference	Clinical study	Linköping University Hospital, Sweden	- 8 consecutive patients from a prosthetic clinic (median age: 39.5 years) - 7 of 8 were below-elbow amputees		- All were conventional myoelectric prosthesis users (on average 3.5 years) - All used adaptive hand for 12 months (first 2 months mostly using adaptive hand, using both from then on)	- Standardized grip function test (by Sollerman) - Differences between the two prostheses analyzed using Wilcoxon's signed rank test - Interobserver correlation (Spearman's rank correlation coefficient) was high, $r_s = 0.97$	- Scores from the standardized grip function test with conventional myoelectric hand were significantly better than the scores with adaptive hand ( $p < 0.01$ ) - Interobserver correlation (Spearman's rank correlation coefficient) was high, $r_s = 0.97$ - Width & force of grip were significantly greater with conventional myoelectric hand compared to adaptive hand - Maximum circumference of closed hand & weight of hand were less for the conventional myoelectric hand - All patients preferred conventional non-adaptive myoelectric hand over the adaptive hand for future use
<b>Datta D, 1991</b>  <b>EBPG Level of Evidence: 4</b>	Reviewing prosthesis use, wearing patterns, ADL, employment & information/counseling status of 55 new upper limb amputees attending a rehabilitation centre in five-year period, in Sheffield, UK	Descriptive review and surveys (questionnaire and telephone)	Amputee rehabilitation centre, Sheffield, UK	55 upper limb amputees were reviewed (of whom 20 were adults, 96% had prostheses)  35 (using a non-electrically powered prosthesis, not lost to follow up, not deceased) received questionnaires	Response rate for the questionnaire survey (35 amputees only) was 77%	Minimum 2 years' follow up  Amputees who attended the centre in a 5-year period (January 1, 1984 to December 31, 1988)	- Postal questionnaires, telephone interviews and case note reviews were performed - Info on electrically powered prosthesis users (7) was obtained through another study by the authors	- Non-electrically powered prostheses were used 1-9 hours/day and 2-7 days/week, with higher wearing times in the below-elbow amputee group - Electrically-powered prostheses were used on average 6.6 hours/day and 6-7 days/week - While 16 amputees were identified as 'employable', only 7 of them were employed (43.7%) and 6 of 7 (85%) were using their prosthesis; 3 of 4 unemployed amputees (75%) had abandoned their prostheses; 3 were in a retraining program and 2 were on long-term sickness benefits - Prior to their contact with the centre, 70% of the

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
				7 electrically powered prosthesis users				amputees received very little counseling & information - Prosthesis rejection rate was 27.2% - Loss of non-dominant arm, higher level of amputation, other disabilities, unstable family circumstances, and delay in referral to rehabilitation centre were factors likely to increase prosthetic rejection.
<b>Fletchall S, 1991</b>  <b>EBPG Level of Evidence: 3</b>	Assessing upper limb burn patients before/after amputation & with immediate or early prosthetic fitting	Clinical study	Regional Medical Centre, Memphis, Tennessee, US	- 7 patients who required amputations following burns (6 below-elbow) - Average age: 37.4 years - 6 male/1 female - Average stay at hospital: 30.14 days (Amputations between Dec 1986 and March 1989)			- Assessments of patients before/after amputation (surgeon & occupational therapist evaluated remaining muscle function, possible sites for myoelectric prosthesis use, range of motion, pre-burn home, avocational & vocational activities) - Patient & family informed about the rationale for amputation, prosthesis, training period & follow up in future - Permanent prosthesis was fitted 2 to 3 months after the temporary one	- 4 patients were fitted with prostheses immediately after amputation (3 body-powered, 1 myoelectric) - 3 patients were fitted with prostheses in the first 30 days after amputation (1 body-powered, 1 myoelectric, and 1 electronic system) - All were wearing their prostheses 8 hours/day & 7 days/week - All 7 amputees were able to manage self-care activities (feeding oneself, maintaining hygiene, using toilet with no assistance) by the end of the first two weeks after the prosthesis - Average time between injury & RTW: 6.4 months
<b>Sears HH, 1991</b>  <b>EBPG Level of Evidence: 4</b>	Studying usage patterns of proportionally controlled myoelectric prosthesis and comparing with the amputee's previous prosthesis	Survey (telephone interview)	US	- 48 amputees with Utah proportional hand prescribed were contacted (after ~ 8-9 months) - 33 participated in telephone interviews - 21/33 were below-elbow amputees		- no acclimatization period	- Telephone interviews with 33 amputees - 5-level scale comparison with previous prosthesis (much better, better, same, worse, much worse; from +2 to -2) - Analysis with Student's t-test	- Former digital myoelectric hand users wore the proportionally controlled myoelectric hand longer hours (compared to former body-powered terminal device users and amputees with no previous prosthesis) - For former digital myoelectric hand users 'control of speed & pinch force', 'quickness', 'control' & 'less effort' were valued features of the proportional myoelectric hand - Disadvantages were 'weight' and 'inconvenience'
<b>Datta D, 1989</b>  <b>EBPG Level of Evidence: 3</b>	Assessing amputee and prosthesis characteristics, and rehabilitation outcomes of myoelectric prosthesis users	Clinical study	Nottingham Centre (Trent area, UK)	- Total of 43 amputees with myoelectric hands - 37 participated; 14 were adults - Only 7 were traumatic amputees			- Info on demographic/general and amputation-related health - Info on prosthetic device - Timed performance tests on functioning when using prosthesis - Questionnaires on prosthesis rejection/usage patterns, ADL	- Myoelectric prosthesis rejection rate was 17% in adult amputees & was higher for younger amputees (31%) - 77% of adult amputees were independent in ADL - Employment rates were good for adult amputees - The authors recommended a multidisciplinary approach and specialized/comprehensive facilities for rehabilitation with myoelectric prostheses - Suggested that along with a myoelectric hand, a body-powered prosthesis should also be provided
<b>Roeschlein RA, 1989</b>  <b>EBPG Level of Evidence: 4</b>	Evaluating factors affecting success in upper limb prosthetic use & focusing on the influence of type of prosthesis on successful prosthetic use	Questionnaire survey	Indianapolis, US (3 prosthesis shops and prosthetists)	- Total of 86 long-term upper limb amputees contacted - 48 returned questionnaires - 8 had missing data - analysis based on 40 remaining (mean age at amputation: 30.8)	Response rate: 56%		- 75-item questionnaire on demographic info, amputation-related factors, ADL, reliability & durability of prosthesis and general concerns about the prosthesis - Successful: at least one type of prosthesis used throughout most of the day, everyday - Partially successful: used for certain	- Acceptance of amputation, both at the time of amputation & during the interview, had an effect on prosthetic success - Education & employment status at amputation, time between amputation & prosthetic fitting, number of existing medical conditions prior to prosthetic fitting & perceptions about cost were related with success - Loss of dominant hand, level of amputation, use of temporary prosthesis, and prosthesis training were not

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
				years)			tasks or hobbies - Unsuccessful: either did not use a prosthesis or used it only for cosmetic purposes	related with successful prosthetic use - Time to return-to-work was shortest (6 months) for successful prosthesis users compared to partially successful or unsuccessful users.
<b>Sturup J, 1988</b>  EBPG Level of Evidence: 4	Reviewing prosthesis use and employment patterns of body-powered prosthesis users in Copenhagen	Interviews	Department of Orthopedic Surgery, Copenhagen, Denmark (1970-1986)	- 59 amputees were contacted - Total included: 43 - All had body-powered prostheses - Mean age at amputation: 30 years	- 12 lost to follow up - 4 excluded (3 with myoelectric, 1 with cosmetic prosthesis)	Mean follow up: 7.4 years	- Analysis by Chi Square test	- Mean age for prosthetic users: 38 years; non-users: 32 years (higher tendency of non-use in younger ages) - Below-elbow amputees had higher usage rate compared to above-elbow amputees (90% and 50% respectively, $p < 0.01$ ) - Employment rate among non-users (mostly at skilled and non-strenuous jobs) was higher than the rate for prosthetic users (57% versus 37%; not statistically significant) - Sex, stump pain, time between amputation and fitting or follow up were not related with prosthetic use
<b>Millstein SG, 1986</b>  EBPG Level of Evidence: 4	Assessing the function and acceptance of various body-powered and electrically-powered prostheses in traumatic (work-related) upper limb amputees with different amputation levels	Descriptive review and questionnaire survey	Ontario Workers' Compensation Board	- 314 adult amputees (work-related) - mean age: 49 years - mean age at amputation: 34 years  - 220 of 314 were below-elbow amputees		Mean time period between amputation and follow up study: 15 years	- Review of patient records - Standard questionnaire	- Advantages of electrically-powered prosthesis leading to high acceptance rate (82%) in BE amputees: - comfort (no harness for below-elbow) - cosmetic appearance - superior pinch force - more natural control - some sensory feedback between stump & prosthesis - Disadvantages of electrically-powered prosthesis: - high cost of initial fitting and repairs - need for a specialized prosthetic service centre - insufficient durability - regular battery recharge
<b>Heger H, 1985</b>  EBPG Level of Evidence: 4	Assessing effectiveness of a myoelectric prosthesis program and determining factors related with acceptance or un-acceptance of a myoelectric prosthesis	Descriptive review & questionnaire survey	Workers' Compensation Board Hospital and Rehabilitation Centre in Toronto (1974-1981)	- 164 adult upper limb amputees fitted with electrically-powered prostheses (1974-1981) - Mean age: 39 years - Out of 164, 130 were below-elbow amputees	- 100% responded to questionnaire/ review	Follow up ~ 3 years	- Patient records (reviewed) - Standard questionnaire (mail, telephone, or personal contact)	- After about a 3-year follow up - 80% acceptance by below-elbow amputees - 69% acceptance by above-elbow amputees - 72% acceptance by high-level amputees - No relationship between acceptance & age, time since injury, or previous use/rejection of a cable-controlled prosthesis - Factors leading to acceptance: comfort, function and reasonable appearance of the hand, suitable occupation, and dislike of harness - Factors leading to un-acceptance: unsuitable working conditions, fear of damage to the prosthesis, insufficient function and/or appearance
<b>Millstein SG, 1985</b>  EBPG Level of Evidence: 4	Determining employment status of past amputees from Amputee Clinic of Ontario Workers' Compensation Board;	Questionnaire survey	Amputee Clinic of Ontario Workers' Compensation Board	- 1587 amputees alive & with valid address - 1010 returned questionnaires	Response rate: 64%	Average follow up after amputation: 14 years (1-64 years)	- Questionnaire designed & pre-tested at the Amputee Clinic - Revised version mailed to all of the amputees (with upper, lower and multiple limb amputations)	- Unemployment rate was 2.5 times higher in females - With regard to amputation level, there was no statistically significant difference between respondents and non-respondents - Retirement rate

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
	exploring factors affecting their return to work and directing better treatment programs for future amputees		(all amputees between 1917-1981)	<ul style="list-style-type: none"> <li>- Below-elbow amputees made up 30% of all amputees</li> <li>- 51% working full-time, 5% working part-time, 25% retired, 8% unemployed</li> </ul>			<ul style="list-style-type: none"> <li>- Questions were on demographic status, employment status (pre/post amputation), prosthetic use</li> <li>- SAS package was used for the analysis</li> </ul>	<ul style="list-style-type: none"> <li>- highest in multiple amputations group</li> <li>- lowest in upper limb amputation group</li> <li>- Below-elbow amputees made up 30% of all amputees</li> <li>- Unemployment rate was 2.5 times higher in females</li> <li>- For upper limb amputees the unemployment rate varied by the level of amputation               <ul style="list-style-type: none"> <li>- highest (22%) in above-elbow</li> <li>- lowest (10%) in below-elbow</li> <li>- 18% in partial hand amputations</li> </ul> </li> <li>- Frequent prosthesis users more likely to be employed</li> <li>- Dominant hand loss not related with unemployment</li> <li>- For successful return to workforce, programs should combine medical, prosthetic &amp; vocational services</li> </ul>
<b>Stein RB, 1983</b>  <b>EBPG Level of Evidence: 3</b>	Comparing performance of myoelectric hand, conventional prosthesis (cable-controlled hook) and normal hand	Comparison study	Department of Physiology & Occupational Therapy at the University of Alberta, Canada (1978 to 1980)	<ul style="list-style-type: none"> <li>- 36 unilateral upper limb amputees</li> <li>- 20 with myoelectric hand</li> <li>- 16 with conventional prosthesis (cable-controlled hook)</li> <li>- In total, 24 were below-elbow amputees</li> </ul>		- Average period of use was 1.4 years for myoelectric hands and 12.2 years for conventional prosthesis	<ul style="list-style-type: none"> <li>- Descriptive statistics</li> <li>- Range of motion (ROM) tests</li> <li>- Activities of daily living (ADL) questionnaire</li> <li>- Analysis with Student's t-test (unpaired)</li> </ul>	<ul style="list-style-type: none"> <li>- No significant correlation between the time since fitting &amp; the functional measures of prosthesis use (myoelectric &amp; conventional prostheses combined)</li> <li>- On average, conventional prostheses were worn 14 hours/day &amp; myoelectric hands 9.6 hours/day (statistically significant difference)</li> <li>- On average, ROM scores of myoelectric users were higher than conventional prosthesis users (4.3 vs. 3.6, respectively)</li> <li>- With the myoelectric hand, tasks took twice as long compared to using conventional prosthesis, &amp; 5 times longer compared to using a normal hand (explained by the low voltage battery (6V) of the myoelectric hand)</li> <li>- Average scores on the ADL questionnaire were not different for myoelectric &amp; conventional prosthesis users</li> <li>- 60% of below-elbow amputees preferred to use myoelectric prostheses, 13% used conventional prostheses, and 26% did not use a prosthesis</li> <li>- Concluded that (at least for below-elbow amputees) myoelectric hands should be part of regular health care practice &amp; should be paid for</li> </ul>
<b>van Lunteren A, 1983</b>  <b>EBPG Level of Evidence: 4</b>	Investigating the role of prosthesis in amputee's life; its benefits and burdens	Post-clinical field study	Two rehabilitation centres in the Netherlands (1977-1978)	<ul style="list-style-type: none"> <li>- Total of 42 unilateral, upper extremity amputees</li> <li>- Out of 42, 30 were below-elbow amputees (15 had myoelectric hands)</li> </ul>			<ul style="list-style-type: none"> <li>- Quantitative data (medical data, results from psychological tests, ADL questionnaire and multiple choice questionnaire)</li> <li>- Qualitative data from interviews during two-day home visits</li> </ul>	<ul style="list-style-type: none"> <li>- Below-elbow amputees use grasping function more often than above-elbow amputees</li> <li>- Gripping function is used more by myoelectric hand users compared to body-powered hook/hand users (significance level 0.02)</li> <li>- It is important that prostheses enable motor functions for hobbies, driving/cycling, work, and ADL</li> <li>- 12 of 13 amputees originally fitted with a myoelectric hand (how long ago unknown) still wore them during the field study</li> <li>- 10 of 24 amputees originally fitted with a body-powered hand/hook still wore a body-powered prosthesis</li> </ul>

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
								<ul style="list-style-type: none"> <li>- amputees with a myoelectric hand used their prostheses more frequently compared to amputees with body-powered prostheses</li> <li>- amputees cited lack of harness as an advantage of a myoelectric hand &amp; lack of sensory feedback (and dependence on visual feedback) as a disadvantage</li> </ul>
<b>Herberts P, 1982</b>  <b>EBPG Level of Evidence: 3</b>	Critically evaluating efficiency and results from a myoprosthesis rehabilitation program with a special interest in amputees who became either non-users or limited users of a myoelectric prosthesis by the review year, 1979	Follow up study	Goteborg, Sweden	- 16 below-elbow amputees fitted with a myoelectric prosthesis between 1975-1978		- All amputees fitted with a myoelectric prosthesis between 1975-1978 were examined in 1979	<ul style="list-style-type: none"> <li>- Activities of Daily Living (ADL) tests in the laboratory</li> <li>- Extensive questionnaire</li> <li>- Technical check-up of the prosthesis</li> </ul>	<ul style="list-style-type: none"> <li>- In this 1979 follow up study, of 16 amputees originally fitted with a myoelectric prosthesis <ul style="list-style-type: none"> <li>- 9 were still wearing it</li> <li>- 3 were using a cosmetic prosthesis</li> <li>- 2 were using a hook</li> <li>- 2 were not using a prosthesis</li> </ul> </li> <li>- Acceptance rate was 56% for myoelectric hand vs. 23% for conventional prosthesis (22 were fitted with a conventional prosthesis prior to the start of the myoelectric program)</li> <li>- 5 amputees were fitted with the three-functional myoelectric SVEN-hand</li> <li>- Patients agreed that this type of prosthesis was easy &amp; reliable, and valued additional movements (i.e. pronation and wrist extension/flexion)</li> <li>- Despite its excellent control system, SVEN-hand encountered mechanical problems</li> <li>- Good 'prosthesis acceptance' figures can be obtained if a program is implemented by a skilled team and with proper follow up</li> <li>- Providing an identical, spare prosthesis helps</li> <li>- Microcomputer applications will simplify the fitting procedure and introduce proportional control</li> </ul>
<b>Millstein S, 1982</b>  <b>EBPG Level of Evidence: 4</b>	Determining the reasons why a small group of below-elbow amputees fitted with myoelectric prostheses became limited- or non-users and getting insights in predicting unsuccessful users of the future	Follow up study  (before/ after myoelectric prosthesis)	Ontario Workmen's Compensation Board Hospital and Rehabilitation Centre	<ul style="list-style-type: none"> <li>- 128 fitted with myoelectric prosthesis by Sept 1981</li> <li>- 25 had stated rejection or rare use, had failed to return the myoelectric prosthesis, or had failed to return for interview (mean age: 41 years)</li> <li>- 22 out of 25 were contacted and reviewed</li> <li>- 63% had dominant-side injury</li> </ul>		- Average follow up between fitting & review: 33 months	<ul style="list-style-type: none"> <li>- Standardized questionnaire used (telephone &amp; in person interviews)</li> <li>- Degree of acceptance of myoelectric prosthesis in terms of function (activities of daily living and vocational / avocational activities), cosmesis, and comfort were measured</li> <li>- Myoelectric prostheses were compared with cable-operated prostheses</li> </ul>	<ul style="list-style-type: none"> <li>- Both non-users &amp; limited users rejected using their myoelectric prosthesis at work (concerned with damaging it); instead, 84% used their cable-operated hooks</li> <li>- 80% of limited users were concerned about cosmesis, whereas only 33% of non-users were</li> <li>- Limited users indicated high cosmetic value of the myoelectric prosthesis when used during social events</li> <li>- Half of the amputees from the limited user and non-user groups mentioned the weight of the myoelectric prosthesis as a concern</li> <li>- The major reason for non-users rejecting the myoelectric prosthesis was its poor functional value</li> <li>- The authors suggested that a myoelectric hook (instead of a hand) might be a solution</li> </ul>
<b>Agnew PJ, 1981</b>	Comparing the functional effectiveness of a	Case report	Department of Occupational	Female post-traumatic below-elbow amputee,			- Two testing sessions per day, for 30 days (she was tested 30 times wearing	- The split hook was functionally better than the myoelectric prosthesis ( $p < 0.001$ )

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
<b>(Functional Effectiveness)</b>  <b>EBPG Level of Evidence: 4</b>	myoelectric prosthesis with sensory feedback to a split hook (Hosmer-Dorrance split hook)		Therapy, University of Queensland, Australia	who was 34 at the time of accident (1975)  Experienced user of split hook; volunteered to be fitted with a myoelectric hand with sensory feedback (1978)			each prosthetic device: a myoelectric prosthesis with sensory feedback & a split hook- Tests used in determining functional effectiveness: Minnesota Rate of Manipulation Placing Test & Smith Test of Hand Function - The order of the tests & prostheses were randomized - First order autoregressive model used for the analysis	- The author noted that based on the clinical evidence, the myoelectric hand with sensory feedback was valuable and preferred for executing certain tasks
<b>Herberts P, 1980</b>  <b>EBPG Level of Evidence: 3</b>	Describing clinical routines, and evaluating functional capacity and acceptance of hand prosthesis in below-elbow amputee patients who attended a rehabilitation program	- Interviews 1-12 years after application of first myoelectric prosthesis - Comparing test and clinical results	Department of Orthopaedic Surgery, Goteborg, Sweden	- 38 unilateral below-elbow amputees - 16 with training on myoelectric prosthesis - 22 without training	- 1-4 years later 9 of 16 (who had prosthetic training) were still using myoelectric prosthesis	- Follow up was 1-4 years (mean 2.4 years)	- Upper extremity function test & a series of ADL activities were applied (scores 0 to 3, high ADL use means 'regular daily prosthesis use') - Compared functional performance scores of trained myoelectric prosthesis users to 1 untrained myoelectric prosthesis user & 2 trained conventional prosthesis users - Also compared test scores with respect to 'grading of acceptance' - 'True use' was measured by battery drain & prosthesis wear (no event counter for grip). Based on extent of use, identified 3 groups (regular daily users-confirmed by battery drain & wear; regular daily users-who claim to be so, but not confirmed; and occasional users).	- After 1-4 years follow up (mean 2.4 years), 9 of 16 trained (56%) & 5 of 22 untrained (23%) amputees were still using their myoelectric prosthesis - 5 out of 9 users found training at first application useful, 1 found it unnecessary, 2 had no opinion - Functional performance scores were poorly correlated with level of acceptance - Extensive prosthesis use can happen despite poor performance on functional tests - If a patient is obviously not using their myoelectric prosthesis, they should be prescribed another prosthesis - Training at the first application enables proper use - Special care and follow up increases acceptance - The authors conclude that access to qualified technical service, a spare prosthesis, & follow up were important for prosthesis use/acceptance - For future prosthetic hand technologies, patients asked for increased number of movements & for some kind of sensory feedback when using their prosthesis
<b>Northmore-Ball MD, 1980</b>  <b>EBPG Level of Evidence: 4</b>	Investigating for how long myoelectric prostheses were used at the workplace, at home, and when out in society, and how the extent of use compared to use of other types of prostheses	- Interviews	Workmen's Compensation Board of Ontario's myoelectric program  (1974-1978)	- 59 compensated below-elbow amputees fitted with myoelectric prostheses - 43 interviewed	- 16 amputees denied the interview  (authors claim that they are not different from the responding ones)	- Mean follow up: 16 months (1974-1978)	- Interview questions were about myoelectric prosthesis use at the workplace, at home, and in society - Same questions asking retrospectively about the period prior to myoelectric prosthesis fitting - Comparisons of before/after - Comparisons with hook/functional hand/no prosthesis	- After myoelectric hand, use of hook at workplace and use of 'functional hand' out in society declined - In society, myoelectric prostheses are used switched off (cosmetic use) & at work mean # of grasps was higher with myoelectric prosthesis (functional use) - Rejection rate (myoelectric hand): 3-8% - Numbers based on conversations with the amputees - Positive attitude towards use of myoelectric hand is because of its appearance, function & lack of harness - Modifying factors: job type, age at accident, capability of using a cable-operated hand - The authors suggest that myoelectric hand research should focus on motor function (e.g. finger control, durability), rather than sensory feedback
<b>Lewis EA, 1975</b>	Evaluating some experimental external prosthetic components and	Crossover Before/after	The Veteran Affairs Research Centre for	- 84 amputees working with 18 clinical teams - Users already	- 69 out of 84 amputees completed the 3-	- 3-month test period	- 84 amputees (already experienced users of body-powered prostheses) were fitted with new prosthetic	- After the study termination, 10 of 15 VA/NU myoelectric hand users chose to continue with it - The VA/NU hand needed less effort to operate

Study	Topic / Objective	Study design	Setting	Subjects	Response rate/ drop outs	Acclimation/ follow up period	Methods	Results/comments
<b>EBPG Level of Evidence: 3</b>	educating the clinical prosthesis teams on these emerging upper limb prosthetic components	study	Prosthetics, 18 Clinical Team settings, USA (1971-1973)	experienced with conventional body-powered prostheses were fitted with new components	month test period		<p>components</p> <ul style="list-style-type: none"> <li>- 69 amputees completed the 3-month test period</li> <li>- 15 of those tested were fitted with VA/NU myoelectric hand</li> </ul>	<ul style="list-style-type: none"> <li>- Terminal device was easier to position &amp; control</li> <li>- More naturally controlled</li> <li>- 'Lack of harness' was appreciated</li> <li>- Provided better cosmesis</li> <li>- Disadvantages: inadvertent operation of the device, slow speed, noise, limited lifting power (not strong enough), and weight</li> <li>- Decision about 'prosthetic type' should be made individually for each amputee, taking into account limitations of the device</li> <li>- Specialized education in fitting these new prosthetic components is important &amp; fitting could be performed in 'a few centralized fabrication facilities'</li> <li>- The clinical team should play a crucial role in prosthetic choice</li> </ul>

## Appendix 4 Factors related to successful prosthetic use/acceptance [Y= yes (related), N= no (not related), C= controversial/unresolved]

Study	Sex	Age	Age at amp / acc / fitting	Edu at amp	Emp	Emp at amp	Job / working conditions	Level of amp	Amp side	Type / properties of prosth (function, appearance, comfort)	Use of temp / imm prosth	Time btw amp & prosth fitting	Training on prosth use	Other medical condition	Availability / continuity of voc/rehab services	Psych accept amp / test scores / perceived prosth need	Prosthetic rejection rate
Herberts P, 1980													Y		Y(con rehab)		44% (trained)
Northmore-Ball MD, 1980			Y (young at acc)				Y					N					8% (myo) BE
Agnew PJ, 1981										Y(split hook)							
Herberts P, 1982										Y (mechanical hooks)					Y		
Millstein SG, 1982							Y			Y							9%
Stein RB, 1983								Y(BE for myo use)				N					26% (myo)
van Lunteren A, 1983								Y(AE)	N	Y		Y			Y	N	
Heger H, 1985		N				Y				Y							20% (myo)
Millstein SG, 1986							Y	Y(BE)		Y (myo hand)					Y		11% BE
Sturup J, 1988	N	Y (old)						Y(BE)	Y(dom)			N					
Datta D, 1989		Y (adult)						Y(BE)							Y		17% (adult)
Roeschlein RA, 1989		N		Y	Y	Y		N	N(dom)		N	Y	N	Y(>2 con)	N (rehab)	Y	
Datta D, 1991								Y(BE)	Y(dom)					Y(neg)	Y		27.2%
Fletchall S, 1991											Y	Y					
Sears HH, 1991													Y				
Kejlaa GH, 1993		Y (young)					Y	Y		Y		Y		Y		Y	
Silcox DH, 1993	N		N				Y		N	Y		N	N				50% (myo)
Pinzur MS, 1994								Y (BE)			Y	Y					
Jones LE, 1995								Y									
Wright TW, 1995	Y	Y	N					Y(higher for BE)	Y(dom)	Y(myo hand)		N (1 <sup>st</sup> year or later)					38% (M) 35% (F)
Jones LE, 1996		N						Y		Y		Y			Y		
Gain WJ, 1997							Y		N			Y					35% (myo)
Hacking HGA, 1997						N		Y (BE)	Y(dom)	Y(active prosth)		Y					21%
Kyberd PJ, 1997	Y(M)							Y (TR)	Y(right)	Y(mechanical hands/hooks)	Y						

\*acc=accident, accept=acceptance, ADL=activities of daily living, AE=above-elbow, amp=amputation, BE=below-elbow, bp=body-powered, btw=between, con=continuous, conv=conventional, cosm=cosmetic, dom=dominant, edu=education, emp=employment, F=female, imm=immediate, inj=injury, M=male, myo=myoelectric, neg=negatively related, pedi=pediatric, prosth=prosthetic, psych=psychological, rehab=rehabilitation, ROM=range of motion, RTW=return to work, temp=temporary, TR=transradial, voc=vocational

Study	Sex	Age	Age at amp / acc / fitting	Edu at amp	Emp at amp	Job / working conditions	Level of amp	Amp side	Type / properties of prosth (function, appearance, comfort)	Use of temp / imm prosth	Time btw amp & prosth fitting	Training on prosth use	Other medical condition	Availability / continuity of voc/rehab services	Psych accept amp / test scores / perceived prosth need	Prosthetic rejection rate
Kyberd PJ, 1998							N		N							5.4%
Biddiss E, 2007 Upper-limb prosthetics	Y(M)	Y			N		Y(TR)	N	Y		Y	Y		Y	Y	16% (TR)
Biddiss E, 2007 Upper limb prosthesis use and abandonment (systematic review)									N (adults) Y (children)							45% (pedi-bp) 35% (pedi-myo) 26% (adult-bp) 23% (adult-myo)
Biddiss E, 2007 The roles of predisposing characteristics	Y	Y (ado-lescents)	N		C		Y	N			Y C (myo)	C	C			
Kyberd PJ, 2007							Y		Y							
Pylatiuk C, 2007							Y									
Biddiss, EA, 2008		Y					Y		Y		Y			Y	Y	
Berke GM, 2010	N	N					Y (upper limb)		Y			Y				
McFarland LV, 2010							Y		Y (mechanical / bp devices)							23% (Vietnam) 45% (OIF/OEF)

\*acc=accident, accept=acceptance, ADL=activities of daily living, AE=above-elbow, amp=amputation, BE=below-elbow, bp=body-powered, btw=between, con=continuous, conv=conventional, cosm=cosmetic, dom=dominant, edu=education, emp=employment, F=female, imm=immediate, inj=injury, M=male, myo=myoelectric, neg=negatively related, pedi=pediatric, prosth=prosthetic, psych=psychological, rehab=rehabilitation, ROM=range of motion, RTW=return to work, temp=temporary, TR=transradial, voc=vocational

## Appendix 5 Factors related with successful return-to-work in the context of prosthetic use

[Y= yes (related), N=no (not related)]

Study	Sex	Age	Age at amp	Edu status at amp	Emp status / job type at amp	Level of amp	Amp side	Use of temp / immediate prosth	Time btw amp & prosth fitting	Regular prosth use / success / acceptance	Available voc / rehab services	Average time btw inj / amp & RTW	Psych state	Return to work (RTW) rate
Millstein SG, 1985	Y (M)		Y (young)	Y	Y	Y (BE)	N			Y	Y		Y	
Millstein SG, 1986										Y (68%)				
Sturup J, 1988										Y (neg)				
Datta D, 1989										Y				
Roeschlein RA, 1989										Y				over 50%
Datta D, 1991										Y				
Fletchall S, 1991								Y	Y			6.4 months (after amp)		over 85%
Pinzur MS, 1994								Y	Y					
Jones LE, 1995										Y				
Wright TW, 1995	Y (M)	Y (young)				Y (BE)				Y				
Gainie WJ, 1997									Y					

## Appendix 6 Comparison studies (myoelectric hand vs. conventional body-powered prosthetic devices)

Study	Level of amp (BE)	Better function (ROM)	Longer / more frequent daily use (hours/day)	Longer time required in completing functional tasks	Average score on ADL	Better appearance (cosmesis)	More weight	Lack of harness (better)	Preferred for unsuitable working conditions	Superior pinch force	Better acceptance	Better durability	High cost initial / maintenance
Lewis EA, 1975				myo		myo	myo	myo					
Stein RB, 1983	myo (60%)	myo	conv bp	myo	no difference								
van Lunteren A, 1983		myo (gripping)	myo										
Heger H, 1985		myo				myo			conv bp				
Millstein SG, 1986	myo					myo		myo	conv bp (hook)	myo	myo	conv bp	myo
Datta D, 1989	myo	conv bp (split hook)				myo	myo	myo		myo		conv bp	myo
Sears HH, 1991										myo (proportional control)			

\*acc=accident, accept=acceptance, ADL=activities of daily living, AE=above-elbow, amp=amputation, BE=below-elbow, bp=body-powered, btw=between, con=continuous, conv=conventional, cosm=cosmetic, dom=dominant, edu=education, emp=employment, F=female, imm=immediate, inj=injury, M=male, myo=myoelectric, neg=negatively related, pedi=pediatric, prosth=prosthetic, psych=psychological, rehab=rehabilitation, ROM=range of motion, RTW=return to work, temp=temporary, TR=transradial, voc=vocational