

## Upper limb prosthetic maintenance data – A retrospective analysis study

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### Abstract

**Introduction:** Understanding repair patterns of upper limb (UL) prosthetics have received little attention compared to their lower limb counterparts. This study focusses on a retrospective analysis of anonymised UL prosthetic maintenance data to establish if there were any patterns of repairs at a regional prosthetic limb-fitting centre in the UK. A secondary aim of this study is to describe the patient demographics of this centre.

**Methods:** Data containing prosthetic repair log and demographic description (n = 212) were acquired through our clinical partners and subjected to statistical analyses.

**Results:** On average, each client visited the centre 0.2 times/year for a new device and 0.9 times/year for maintenance-related activities. It is found that the repair rates are generally higher for body-powered devices (1.28 visits/device/year) compared to passive (0.94 visits/device/year) and externally-powered devices (0.90 visits/device/year). In keeping with the typical UK UL-deficient population, there is a high male-to-female ratio, and higher instances of traumatic amputations were noticed for males at the centre. There is a very high preponderance of congenital cases and an overall emphasis on prescribing passive devices to a majority of patients at the centre.

**Conclusions:** The data from our study are similar to previously published data from other centres and show a consistent pattern in terms of relative rates of maintenance attendances for different types of UL prostheses.

**Keywords:** Amputation, Artificial Limbs, Demography, Maintenance, Retrospective Studies, United Kingdom, Upper Extremity

**Word count:** 6070 (excluding references)

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### **Relevance or significance of the study:**

1. This study provides a longitudinal perspective and insights on ever-changing requirements (prostheses and related care) of the users at the level of a regional limb-fitting centre.
2. This study underscores current gaps in prosthetic device durability/reliability and opens up avenues for improvement of prosthetic services and devices.
3. Insights on the repair patterns and device durability have implications towards design improvements for limb manufacturers, providing device warranty, policy changes, among others to improve prosthetic outcomes.

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## Introduction

Numerous surveys have captured the needs, satisfaction levels, priorities, and concerns of both current and prospective upper limb (UL) prosthesis users.<sup>1-7</sup> Unfortunately, low usage and device abandonment persist among a minority of these users.<sup>1,4</sup> Additionally, the cost of a prosthesis, repeated mechanical failure, and the frequency of repairs/replacement have been linked to reduced satisfaction levels.<sup>1,6-9</sup> In the lifecycle of a prosthesis, both durability and reliability become factors that can drive up the cost of prosthetic usage.<sup>8,10</sup> More durable prostheses have been desired that require fewer repairs.<sup>1,6-8,11-12</sup> However, this necessitates a clearer understanding of the current device durability and repair patterns, which could also inform the requirements for future prosthetic designs.

Prescription of a prosthesis currently depends to varying degrees on patient input, the experience of treating clinicians with available components, the literature on component function, manufacturer's claims, and reimbursement methods.<sup>7,13</sup> Insurance coverage policies and funding for UL prostheses (and the associated repair/maintenance costs) vary remarkably and result in strikingly different adoption rates, particularly for active UL prosthetic technologies (i.e. body-powered (BP) and externally-powered (EP) devices), among different countries<sup>14</sup> as well as within a country.<sup>15-16</sup> However, veterans seem to be an exception to this norm in most countries.<sup>10,17</sup> Impact of acquired UL loss and prosthesis use on healthcare costs is an understudied topic due to the lack of adequate population size and data sources. It was estimated every \$1 spent on rehabilitation (including prosthetic care) saves more than \$11 in disability benefits alone, and offers numerous non-fiscal benefits to the patient.<sup>18</sup> Although the benefits of prosthetic use could well outweigh its cost,<sup>19</sup> the prosthetic application is part of an overall expensive rehabilitation process. A plethora of studies have explored the costs associated with

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lower limb (LL) prostheses, and their UL counterparts have received some attention only in the most recent decades.<sup>8,10,20–24</sup>

The data on prosthetic purchasing and repair is sparse and is often dependent on self-reported data.<sup>7</sup> Self-reported data on UL prosthetic replacement rates range from one to five years between replacements.<sup>24,25</sup> One study reported that patients visited a prosthetist on average, nine times a year.<sup>26</sup> Nevertheless, relying solely on self-reported data on prosthetic maintenance has its own set of limitations, e.g. recall bias or social desirability bias. It is challenging to get data on prosthetic provision and repairs from the device supplier, which could be commercially-sensitive data. Patients' medical records often contain valuable information about the changes that the individual and the prosthetic service have undergone longitudinally, as evident in earlier studies.<sup>27–30</sup>

Past studies (excluding self-reports, questionnaire-based surveys or interviews) assessing the costs and/or repair patterns associated with UL prostheses and capturing the patient demographics have involved analysing veteran database<sup>10,21–22</sup>; insurance claims database<sup>20</sup>; a retrospective analysis of the clinical records from a regional prosthetic rehabilitation centre<sup>27–31</sup>; use of secondary data from a local UL prosthetic clinic database<sup>32</sup>; use of data from Workers' Compensation Board<sup>23</sup>; a combination of expert consensus, survey questionnaires, and Medicare price guidelines to project future prostheses costs,<sup>24</sup> etc. There is very little literature about UL prosthetic repair rates, particularly in the UK. The objective of this anonymised UL prosthetic maintenance analysis study is to establish if there were any patterns of repairs (in terms of frequency and types of maintenance-related activities) in the region for age, gender, and device types and describe the demographics of the patients treated at the regional limb-fitting centre.

## Methods

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This study did not require ethical approval, as no patient participation or access to identifiable information was necessary. An anonymised dataset was obtained from the regional prosthetic limb-fitting centre at the Oxford Centre for Enablement (OCE), Nuffield Orthopaedic Centre, Oxford University NHS Foundation Trust. The OCE is the only Level 1 unit that is funded by National Health Service England (NHSE) for the ‘Thames Valley and Wessex region’ which covers a wide ‘catchment’ area (from Oxfordshire, Buckinghamshire, Berkshire, Hampshire, Isle of Wight, and Dorset).<sup>33</sup> The data (from 01/01/2013 to 31/12/2018) obtained for each of the patient visits were classified into different categories. The following definitions were followed for classification of visits related to the prosthesis:

- **Minor repair** – anything that can be done while the patient waits (e.g. work content up to about 3 – 4 hours)
- **Major repair** – anything that requires the prosthetic arm or part of the arm to be kept in the department for at least one night (e.g. anything that requires parts to be ordered in or anything with a longer work content than can be done as a minor repair)
- **Supply of new item(s)** – anything where a patient simply requires an item or set of items (e.g. components such as a new glove, new elastic bands for a split-hook, new split-hook)
- **New socket** – a new socket (i.e. the custom-made section that directly interfaces with the patient’s residuum) is required, usually, due to changes in residuum shape.
- **New limb** – a whole new limb (or prosthetic device) is required

Any visit during the six years preceding 31/12/2018 for either prosthetic repair (major repair, minor repair, a supply of new item(s) or supply of new socket) or supply of a new limb was included. This resulted in a relevant patient population of n = 212 (114 males (54%) and 98 females (46%)), distributed across all different levels of UL loss/absence (from forequarter

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disarticulation to the level of digits). The dataset was based on the prosthetic repair log for anonymised patient IDs (see Supplementary Material). Maintenance data were included for all UL prostheses issued to patients in recent years (e.g. date of first issuance and dates of a patient visit to the centre for maintenance-related activities, readjustments, re-fittings, re-trials of their prosthesis after the first issuance, etc.). The UL deficiency type was categorised as *below-elbow* (BE category containing all UL deficiency levels distal to elbow disarticulation), *above-elbow* (AE category containing all UL deficiency levels proximal to and including elbow disarticulation), and *UL congenital abnormality* (ULCA). Justifiably, these generalisations were carried out as the total number of patients (n = 212) when classified into different categories (such as device type, age groups, repair type, etc.) *and* the numerous levels of limb loss/absence would have led to very small numbers in each of the categories disallowing any meaningful comparisons. The ULCA patients warranted a separate analysis—discrete from transradial and transhumeral levels of limb absence—for the following reasons provided by the clinical team at the OCE who helped create the prosthetic repair dataset and categorised this subset of the congenital patients as ‘ULCA.’ In the vast majority of cases, the ULCA patients will have a level of limb absence that does not fit into a simple ‘transradial’ or ‘transhumeral’ type categorisation. For example, they may have a longitudinal deficiency, or they may have a segment shortening with unusual anatomy of the segment distal to that (e.g., a shortened forearm with only three digits and a wrist with limited range of movement).

Dataset obtained from our regional clinical partners was formed by combining several different databases wherein all duplicate entries were removed. It is assumed that there is no under-reporting of prosthetic maintenance-related visits, and there was minimal loss of information when the different databases were combined to create the maintenance dataset. All



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subsequent analyses were performed using MATLAB® R2019b (Mathworks Inc., Massachusetts, USA). The number of repairs of each maintenance-related activity (Figure 3) was counted separately for all three types of prostheses, i.e. passive, body-powered (BP), and externally-powered (EP) devices, for both paediatric (<18 years) and adult groups, whilst separated into different levels of UL loss/absence. Each number of repairs were then normalised by having them divided by the corresponding number of devices at the same limb-deficiency level in the same age group, e.g. the number of repairs for passive device users, aged <18 years, in the AE category, was normalised by having them divided by the number of passive devices belonging to users, aged <18 years in the AE category. The normalised repair numbers were then compared between different device types at different levels of limb deficiency for different age groups.

Previous studies have defined ‘active’ users registered with the limb-fitting centre as those who have made contact with the centre at some point in the past two years<sup>27</sup> (at the Oxford limb-fitting centre) or past three years<sup>34</sup> (at the Cambridge limb-fitting centre). In this context, the term ‘active’ means whether the prosthesis is used sufficiently to require replacement or repair. The frequency of repair is calculated by the total number of repairs divided by the number of years of possession of the prosthesis by a patient.

Due to the small sample size of patients when categorised into different groups, the results were analysed at a descriptive level rather than examining the statistical significances for most Demographic/personal factors, Upper limb deficiency-related factors, Prosthesis-related factors, and Maintenance-related factors. However, a Pearson Chi-square test was carried out where applicable, assuming even distribution between the relevant categories from the dataset in the null hypothesis. The statistical significance ( $\alpha$ ) level set at 0.05, whilst p-values are not reported for results that are not statistically significant. Finally, a Pareto analysis of the frequency

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of annual visits for patients with at least two years of prosthetic usage was performed. See the Supplementary Material for a GitHub link for accessing the MATLAB codes for data analysis and a Microsoft Excel spreadsheet template for building a dataset similar to the one used this study.

### Results

#### *A. Demographic/personal factors – Sample population*

The male-to-female ratio for the sample population was 1.16:1; the same ratio was 1:1 for the paediatric group and 1.21:1 for adults. The mean  $\pm$  SD age of the paediatric group ( $n = 46$ ) was  $8.8 \pm 4.7$  years with a range of 1 – 17 years, while that of the adult group ( $n = 166$ ) was  $54.3 \pm 18.6$  years with a range of 19 – 91 years. In the Supplementary Material, Figures S.1 and S.2 show the profile of the ages and the gender distribution of the analysed patients compared to an earlier study at the same centre.<sup>27</sup>

#### *B. Upper limb deficiency-related factors – Aetiology, side, and level of deficiency*

In Table 1, the most common aetiology of UL deficiency in our centre was congenital ( $n = 90$ ; 42%) followed by ‘Unknown’ cause ( $n = 50$ ; 24%) and trauma ( $n = 42$ ; 20%). There was a higher number of females than males for congenital UL absence at the OCE, and the total female-to-male ratio for this group was 1.14:1. This ratio was 0.91:1 for the paediatric group and 1.52:1 for adults.

*Insert Table 1 about here*

All the cases with an ‘Unknown’ aetiology comprised of adult patients. Notably, the cause was likely labelled ‘Unknown’ for these patients as the relevant information was not available in the official record used to create the dataset and the reasons for this is not known to the study team. In total, there were 42 patients (20%) with traumatic amputations, although 95%

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of these patients were adults. There was a high preponderance of males with traumatic amputations with a male-to-female ratio of 2:1 (Pearson Chi-square,  $p < 0.05$ ) in our centre. It can be seen that adults constituted a significant majority of analysed patients with an acquired UL deficiency (Pearson Chi-square,  $p < 0.001$ ) due to trauma, infection, dysvascular conditions, neoplasia or neurological conditions. Table 1 shows very high cases of congenital UL absence on the unilateral left side compared to the unilateral right side (Pearson Chi-square,  $p < 0.05$ ). In both these cases, there was a higher number of females than males. There was a higher number of acquired limb loss on the unilateral right side due to trauma compared to the unilateral left side at the OCE.

The most common level of UL loss/absence (Supplementary Material, Figure S.3) in the sample population was transradial level ( $n = 96$ ; 45%), followed by ULCA ( $n = 33$ ; 16%), transhumeral level ( $n = 30$ ; 14%), and partial hand ( $n = 24$ ; 11%). Out of the 90 congenital patients, 33 patients were classified by the clinical team as ULCA, and the remaining 57 patients had a level of limb absence that can be categorised as transradial, transhumeral, etc. In total, there were 199 individuals (94%) with unilateral UL deficiency (107 unilateral left (51%) and 92 unilateral right (43%)) and 13 individuals (6%) with bilateral UL-deficiencies.

### *C. Upper limb deficiency-related factors – Time of device fitting*

The mean  $\pm$  SD age of first fitting for congenital cases ( $n = 35$ ) was  $1.31 \pm 1.25$  years, and the mean  $\pm$  SD time elapsed between limb amputation and device fitting for cases with acquired limb loss ( $n = 39$ ) was  $0.57 \pm 0.51$  years.

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### *D. Prosthesis-related factors – Type of prostheses and terminal devices*

In total (Table 2), 72% of the devices were passive ( $n = 168$ ) (Pearson Chi-square,  $p < 0.001$ ), 20% were BP ( $n = 47$ ), and the remaining 8% were EP ( $n = 18$ ). Seventeen of the 199 individuals (8%) with unilateral UL deficiency employed more than one prosthesis – (i) six patients with a passive and an EP device; (ii) three patients with a BP and an EP device; (iii) seven with a passive and an EP device; and (iv) and one patient used all three types of prostheses. None of the patients with bilateral UL-deficiencies used more than two prostheses (i.e. one prosthesis on each arm).

Fifty per cent of the TDs were either passive hands (anthropomorphic) or split-hooks (Supplementary Material, Figure S.4). Another 21% of the TDs were passive task-specific; BP hands or hooks constituted 21% of the TDs followed by 7% EP hands or hooks. A detailed breakdown of patients with multiple prostheses and/or terminal devices (TDs) is given in Supplementary Material (Table S.1). The number of patients with unilateral UL deficiency using multiple TDs ( $n = 21$ ; 10%) ranged from two to four. Two patients with bilateral UL-deficiencies had more than two TDs. For patients using multiple TDs, passive hand and hooks were the most common TDs followed by BP hook and EP hand.

In this study, 59 patients received their first prosthesis fitted in the considered period. Out of these 59 patients – 53 patients received passive devices (26 paediatric and 27 adult patients) (Pearson Chi-square,  $p < 0.001$ ); four patients received BP devices (four adult patients); two patients received EP devices (one paediatric and one adult patient). The only paediatric patient equipped with the EP device had the first device fitting at the age of nine years and was then equipped with a passive device (with a task-specific and an anthropometric TD) within the next eight months.

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### *E. Maintenance-related factors – Frequency of visits and Date of last contact of patients at the centre*

The anonymised dataset for 212 patients contained a total of 1407 maintenance-related visits to the centre (i.e. Minor repair = 334; Major repair = 448; Supply of new item(s) = 315; Supply of new socket = 51; and Supply of new limb = 259). The average frequency of visits to OCE by a patient per device per year (averaged over six years) is detailed in Table 2. It was found that the repair rates were generally higher for BP prostheses (1.28 visits/device/year) compared to passive (0.94 visits/device/year) and EP prostheses (0.90 visits/device/year). Female patients visited the centre for maintenance-related activities more than male patients for both passive and BP devices, although this finding was not statistically significant.

*Insert Table 2 about here*

The top ten patients who paid the most trips to the centre consistently over six years on an average needed six repair-related visits/year (Range: 5 – 10 visits; SD: 2 visits; Max: 10 visits). On average, each client visited the centre 0.2 times/year for a new device and 0.9 times/year for maintenance-related activities. In Figure 1, 73 patients (34%) visited the centre 0 – 0.5 times/year (i.e. zero to one visit in two years), and 45 patients (21%) visited the centre 0.5 – 1 times/year (i.e. one to two visits in two years). However, 36 patients (17%) made 2 – 10.5 annual visits to the centre. The median value of 0.67 annual visits/patient to the centre is observed. With a Pareto analysis (Figure 1), it can be seen that 80% of the patients annually visited the centre 0 – 2 times. However, the remaining 20% of the patients made much higher repair-related visits.

*Insert Figure 1 about here*

The number of ‘active users’<sup>27</sup> (Figure 2) based on the date of the last contact with the centre, within last two years of our data collection were 118 (55%) or within last four years of our data collection were 167 (79%).

*Insert Figure 2 about here*

### ***F. Maintenance-related factors – Repair patterns***

Figure 3 summarises the UL prosthetic maintenance data at our centre for the considered period. In adults, BE category with 127 patients (60%) was the largest group, followed by AE category with 36 patients (17%). There was a majority of passive devices (71%) followed by BP devices (19%) in the adult BE category, and a substantial number of patients were fitted with active devices, i.e. BP and EP devices ( $n = 37$ ; 29%). Highest repair rates were found for BP devices, especially for minor repairs (0.46 visits/patient/year) and major repairs (0.69 visits/patient/year).

*Insert Figure 3 about here*

For the adult AE category, there were a higher number of passive devices (58%) fitted compared to BP devices (42%), and there were no EP devices. The rates of minor repairs and major repairs were higher for BP devices compared to passive devices. Request for new limbs was higher in the BE category compared to the AE category. Across the five different types of maintenance-related activities, the repair rates for this category were mostly either equal or less than the repair rates for the adult BE category. The adult ULCA category was dominated by passive devices (85%).

For paediatric prosthesis users in the BE category, much higher passive devices were fitted (86%) followed by BP devices (14%). The frequency for new devices requested for the paediatric group was almost twice as high as that for the adults, which could be attributed to their constant growth. For ‘ULCA (age <18 years)’ category, it was seen that they have the highest rates of new sockets and new limbs. Notably, there was also a higher repair rate for EP devices across different repair types.

### Discussion

#### *A. Demographic/personal factors – Sample population*

Our study found a similar number of patients in each age group (Supplementary Material, Figure S.1) for those aged up to 49 years, while the numbers increased in the age range of 50 – 79 years which is quite different to the age distribution showed earlier.<sup>27</sup> This study reports a relatively more equal gender distribution (Supplementary Material, Figure S.2) compared to earlier studies carried out at the OCE.<sup>2,27</sup> More males were generally found to be registered with British limb-fitting centres than females in the past.<sup>27,31,35–36</sup>

#### *B. Upper limb deficiency-related factors – Aetiology, side, and level of deficiency*

UL amputations accounted for 8% of all amputations in the UK in 2012, with trauma being the most frequent cause.<sup>37</sup> However, our study presents a higher prevalence of congenital cases which could possibly be ascribed to the age-population profile of the ‘catchment’ area. Such exceptions at British limb-fitting centres were found in earlier studies at Edinburgh<sup>12</sup> and Sheffield.<sup>29</sup> Only 5% of the traumatic amputations were of the paediatric group in our study, in agreement with a British study from Liverpool.<sup>31</sup>

All the ‘Unknown’ cases comprised of adult patients in our study, and the most likely cause of limb loss in this group based on data from other studies has been trauma.<sup>2–4,6,27</sup> There is a higher number of traumatic amputations on the right side, similar to an earlier study.<sup>30</sup> This is thought to be because most traumatic UL amputations are on the right side, which is most probably the dominant side. Hence, it is recommended to separately consider patients with acquired UL deficiency on their dominant side as this might have implications on device use/wear patterns, device repairs, and eventually prosthetic outcomes.

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A high female-to-male ratio is found in both left-sided and right-sided congenital UL absence cases as reported earlier.<sup>27,38</sup> Among those with congenital UL absence, a significant left-side bias is observable, similar to an earlier study.<sup>36</sup> Besides, there are far fewer traumatic losses in females similar to those found earlier.<sup>27</sup> For adult patients, there is a high male-to-female ratio as well as statistically significant traumatic amputations for males consistent with published literature.<sup>2,6,12,23,27,30,39–40</sup> In agreement with an earlier study,<sup>12</sup> there are more individuals with transradial loss than transhumeral loss.

### *C. Upper limb deficiency-related factors – Time of device fitting*

The optimal timing of prosthetic fitting from the first referral varies with each patient and the level/aetiology of UL deficiency. Ideally, the time elapsed between the first referral and device fitting should be as low as possible, which is a predominant predictor of UL prosthesis use. There is no consensus for the age of first prosthesis fitting for children, and most researchers agree to fit a device between 2 – 25 months.<sup>38,41–43</sup> In our study, the age of first fitting for congenital cases is within the recommended two years from birth for most patients. Individuals fitted within six months of acquired UL loss were 16 times more likely to continue prosthesis use,<sup>1</sup> and this timeframe is roughly within six months in our study.

### *D. Prosthesis-related factors – Type of prostheses and terminal devices*

At the OCE, passive devices significantly dominate the device prescription, followed by BP and EP devices consistent with published literature,<sup>6,12</sup> which could be partially explained by a higher number of paediatric prosthesis users as well as how the centre approaches particular patient groups according to one of the co-authors of this article (DHS).

Most children are fitted with either a passive device or a BP device (with voluntary-closing TD) as their first active prosthesis<sup>42</sup> due to durability and affordability reasons. More



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sophisticated or myoelectric devices are rarely prescribed to the skeletally-immature due to both cost and weight constraints. A passive device is the most common first choice of device prescription for paediatric patients at this centre (26 out of 27 patients; 96%) in the considered period. Paediatric patients when allowed to choose a prosthesis type freely, frequently choose a passive device,<sup>44</sup> indicating that appearance may be prioritised over the function of an active TD. Furthermore, 27 out of 32 adult patients (84%) were fitted with a passive device as their first device in the considered period, showing a similar significantly high preponderance of passive device prescription for adult users.

Our study reports that several patients own/use multiple prostheses and TDs. Studies in high-income countries have recorded that many subjects were users of more than one type of prosthesis.<sup>2–3,19,21–22,24,29,32,44</sup> In such a setting, multiple identical prostheses may serve the purpose of ‘backup’ for service and breakdowns, while different prosthesis types and TDs have distinct functional advantages and may supplement each other.<sup>3</sup> It will be interesting to know which device is their primary prosthesis along with how they employ different TDs in their activities of daily living.

### ***E. Maintenance-related factors – Frequency of visits and Date of last contact of patients at the centre***

BP devices are associated with higher repair rates compared to passive and EP devices, as reported earlier.<sup>10</sup> We are limited by the dataset and the retrospective scope of the study, and hence are unable to explain why female prosthesis users have seen much higher repair rates than males. In a recent study,<sup>45</sup> the need for frequent prosthetic service and repair was among the various factors that diminished the desirability of the device for female users. Some patients might exhibit greater diligence about coming to the centre to have the repair done while others

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might adopt a ‘self-repair’ approach to get them by until their next visit to the centre. It could be valuable to understand how different genders approach prosthetic self-repair until their next scheduled appointment to the limb-fitting centre (for especially those facing time, financial, and accessibility constraints).

A mean  $\pm$  SD prosthetic life of  $2.64 \pm 1.3$  years as assessed by the number of repairs and replacements required during the period of active usage has been reported.<sup>9</sup> On average, commercial prosthetic hands were reported<sup>10</sup> to require 0.21 repairs/year with myoelectric devices needing only 0.19 repairs/year, although, these rates of repair were too high for the most committed users. Most prosthesis users considered the frequency of repairs two to three times per year to be satisfactory.<sup>46</sup> In an American report,<sup>47</sup> veterans reported that their prosthetic arms would break often and require frequent repairs – in one case, a veteran described requiring over 100 repairs, adjustments or replacements of his prosthesis within five years since his injury (averaging roughly 20 maintenance-related activities/year). The data from our study are similar to previously published data from other centres and show a consistent pattern in terms of relative rates of maintenance attendances for different types of prostheses.

Kyberd et al.<sup>27</sup> reported 50% of the patients were active, and 80% of patients made contact in the previous four years. In close agreement with this (Figure 2), the number of ‘active users’ in our study, within last two years was 118 (55%) or within last four years of our data collection was 167 (79%). However, to estimate the number of ‘active users’ in our study, the ‘Date of last contact’ information was known only for repair-related work and not for any other forms of contact made by the patient with the centre. Not all prosthetic users treated at the centre might likely have been included in our dataset; it is likely that some of the patients used the postal service for repairs and replacements, and subsequently, made fewer visits to the limb-

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fitting centre to have their prostheses regularly reviewed.<sup>35</sup> In a Cambridge study, Fraser<sup>34</sup> concluded that patients should attend the clinic at intervals of no longer than two years to have their prostheses checked for fit, comfort, and updating. Outcome assessment of prosthetic fitting has been based on the clinic attendance of the patient and parents and the self-reported prosthetic usage;<sup>42</sup> and hence, estimating the number of ‘active users’ or using clinic attendance for prosthetic outcome assessment is recommended as a worthwhile pursuit.

### *F. Maintenance-related factors – Repair patterns*

We generally report higher rates for major repairs than minor repairs – the implications being the prosthesis (or a part thereof) will be required to be kept in the OCE department for at least one night. Hence, major repairs would likely pose higher inconvenience and cost implications for the patient and the centre. BP devices may need more frequent repairs most of which can be done in the office, as opposed to EP devices which usually have to be sent in to the manufacturer for factory servicing (requiring submitting to insurance for the repair costs, if applicable). Similarly, some custom-made passive devices often require touch-ups from the manufacturer, too and cost more. Chan<sup>23</sup> has highlighted that proper routine maintenance by the prosthesis user, and qualified service professionals are critical in maintaining the functional performance of the prosthesis, as well as the personal hygiene of the device user. Routine maintenance includes daily cleaning, alignment checks, adjustment, and functional inspection by the prosthetist. Periodical inspection and preventive maintenance by a prosthetist can prevent catastrophic failures. It will be helpful to understand if the repair-related visits in the centre were due to a device failure or a part of a planned/scheduled maintenance routine.

Adults in the BE category made more repair-related visits than in the AE category, which may be because BE devices are used relatively more for functional purposes, as found in earlier

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studies.<sup>23,48</sup> Users of active prosthesis tend to return to the centre more frequently for repairs, similar to a previous study at the OCE.<sup>27</sup> The number of repairs is the highest for BP devices compared to EP and passive devices, as also concluded earlier.<sup>10,22</sup> BP prostheses have commonly been associated with user complaints on several issues, including cable and harness maintenance issues.<sup>13</sup> Myoelectric devices users have been reported to have higher prescription rates; however, BP users had higher repair rates.<sup>10</sup> Resnik et al.<sup>22</sup> concluded that myoelectric users were more likely to report two or more repairs in the past twelve months as compared to other device type users, and passive device users reported the fewest.

For paediatric prosthesis users at a BE level, a higher number of passive devices (86%) were fitted followed by BP devices (14%). Lower rates of minor repairs and major repairs compared to their adult counterparts were found in the same category. This may be because the devices are not used by some children functionally as much or used for simpler occupational requirements. However, it could also be attributed to the reduced forces applied to the prosthesis due to their lower body weight compared to adults. There is a lack of adaptability in most current prosthetics to the expected growth of children's limbs, thus requiring constant visits to healthcare providers for adjustments or replacement. Prosthetics in children are replaced more frequently, and starting anew with new components could explain requiring fewer repairs.

The analysis by Chan<sup>23</sup> showed high prosthetic failure (repair) rate (viz. once per year) and high demand maintenance (repair, adjustment, and replacement) frequency (viz. 1.7 times/year); these values were found to be approximately the same for BP and myoelectric devices. Reliability is indicated by the frequency of demand maintenance due to malfunctioned parts, out of alignments, and worn-out components.<sup>23</sup> Chan<sup>23</sup> suggested that this high maintenance requirement is likely due to the practice of non-standardised individualised

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fabrication, which combines many off-the-shelf components and customised components.

Inappropriate use of the prosthetic limb beyond its designed capability is another contributing factor. Establishing product standards, practice guidelines, and prescription protocols will improve the reliability of the prostheses. The results from our study provide new data trends on prosthesis maintenance across device types, underscores current gaps in prosthetic device durability/reliability, and opens up avenues for improvement of prosthetic services and devices.

### Study limitations

Several limitations are acknowledged that reduce generalisability and ready adoption of results from this study. The dataset of UL-deficient patients was selected from a single limb-fitting centre (OCE), from a reasonably small geographical region in the UK. Hence, it is likely not to reflect the entire UK population of UL prosthesis users, which increases by over 500 annually.<sup>49</sup> Moreover, according to the Clinical Consultant's experience at the OCE (DHS), the patients treated here are likely to be younger, more affluent, less industrial, less likely to smoke or have accidents resulting in limb loss compared to the national average.

Even though this study offers results for a 'self-selecting group' of prosthetic users, who visit the OCE quite frequently for prosthetic maintenance-related activities, the results of such a study are no less valid as these are the typical individuals most likely to actively and rigorously use a prosthesis. Despite aiding in comparing different groups, the generalisations of categorising the UL deficiency type as BE, AE, and ULCA, are likely to affect the means observed in the two categories unduly.

It is acknowledged that merging repair data for both unilateral ( $n = 199$ ; 94%) and bilateral prosthesis users ( $n = 13$ ; 6%) has likely skewed our findings, albeit to a very small extent due to the significantly higher share of unilateral patients. It was decided to merge this

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data in our study as separating the two would not have been statistically meaningful for the latter group. In future studies, it would be better to separately analyse the repair-related data for bilateral patients as their wear, usage, and breakage patterns are likely to be very different compared to unilateral patients.

We calculated the average number of new devices, repairs, etc., per patient per year in this study. We were unable to examine whether repairs and replacements may have been ordered for more than one prosthesis and/or TD owned by the patient. Future studies are needed to examine the repairs and lifespan of specific types of devices/TDs. This study did not attempt to calculate the actual costs of devices received or repaired, and this information should be sought from manufacturers, healthcare providers, and funders.

### Recommendations for future work

Studies involving prosthesis monitoring outside of the clinical environment over extended periods should be carried out using technology (e.g. sensors on or in the prosthesis) to distinguish and quantify actual prosthesis ‘wear’ and ‘usage’ patterns. This can be implemented via actimetry,<sup>50</sup> determining the number of TD opening/closing cycles<sup>51</sup> or the use of on-board sensing to evaluate the choice of grasp<sup>52</sup> and compared against prosthetic repair/maintenance log data. These data can provide valuable information for prosthetic device development and maintenance. The clinical team should go through individual patient notes and involve qualitative methods (by the administration of open-ended surveys and questionnaires, interviews, and focus groups) with the patient to gather subjective patient-reported information surrounding device maintenance and repair activities. Feedback on device reliability and robustness from users can also be elicited using published outcome measures such as *QUEST 2.0 Survey*<sup>53</sup> or *OPUS Client Satisfaction with Devices Scale*.<sup>54</sup>

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Formal device and repair cost-effectiveness analysis was not the purpose of this article; therefore, future studies could focus on both cost and repair patterns with years of device possession.<sup>20,23–24</sup> Our study utilised prescription and repair of prostheses in a national healthcare system that has universal prosthetic coverage. Availability and prescription of prostheses can be contingent on medical insurance coverage and payer restrictions in a geographical location which can impact prosthetic rehabilitation. Given the rates of prescriptions and repairs found in this study, it is likely that costs would be prohibitive for many prosthetic users, especially in countries without universal prosthetic coverage or caps in insurance plans.<sup>10,14</sup> Further exploration is required in this regard, particularly among populations from low socioeconomic backgrounds in countries without universal prosthetic coverage.<sup>8,30</sup> It will be valuable to understand patterns of repair<sup>10</sup> and barriers to routine maintenance in low-resource settings as the associated costs would undeniably limit access, cause economic hardship, device abandonment and/or non-use and result in diminished participation in society and quality of life. A similar study should be carried out for LL prostheses since the repair rates are higher for individuals with LL deficiency compared to UL deficiency.<sup>10,30</sup> Primarily, this is because LLs in most cases, support the weight of the individual, thus undergoing considerable forces and torques.

Finally, there is a need for central databank that records the changing provision of prostheses concerning the limb-deficient population in the UK, and such information is often fragmented across localised databases in different rehabilitation centres. As the detailed records of these changes are contained in the patients' medical records, it is difficult to analyse these data except on an individual basis; the larger picture requires the scrutinising of data from a centre or many centres. It is recommended that more extensive data collection and analysis of prosthetic maintenance/repairs should be carried out at a (multi)national level.

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## Conclusions

This study focussed on a retrospective analysis of anonymised UL prosthetic maintenance data to establish patterns of repairs (in terms of frequency and types of maintenance-related activities) with age, gender, and device type at the regional limb-fitting centre. A secondary aim of this study was to describe the demographics of the patients treated at this centre. Body-powered devices were found to be associated with higher maintenance-related repair rates compared to other device types. This study is, to our knowledge, one of the very few studies of its kind to assess the rates of UL prosthetic prescription and repair by amputation type and level, device type, age, and gender. The data from our study are similar to previously published data from other centres and show a consistent pattern in terms of relative rates of maintenance attendances for different types of prostheses. A study like this provides a longitudinal perspective and insights on ever-changing requirements (prostheses and related care) of the users at the level of a limb-fitting centre. Additionally, this study establishes patterns of device repair/maintenance in a region sheds light on device durability. Finally, this study underscores the fact that the use of maintenance records seems to be a valuable source of information complementing traditional subjective and objective measures of prosthetic outcomes.

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## Declaration of interest



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The authors report no conflicts of interest.

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### Figure legends

**Figure 1.** Pareto analysis of the frequency of annual visits for patients with at least two years of prosthetic usage

(Note: Only patients with first prosthetic fitting before 01/01/2017 are considered here)

**Figure 2.** 'Active' users based on the date of last contact by patients at the centre (Note: 'Repair' in this figure refers

to major repair, minor repair, supply of new item(s) or supply of new socket)

**Figure 3.** Upper Limb Prosthetic Maintenance Data (01/01/2013 to 31/12/2018)

Figure 1

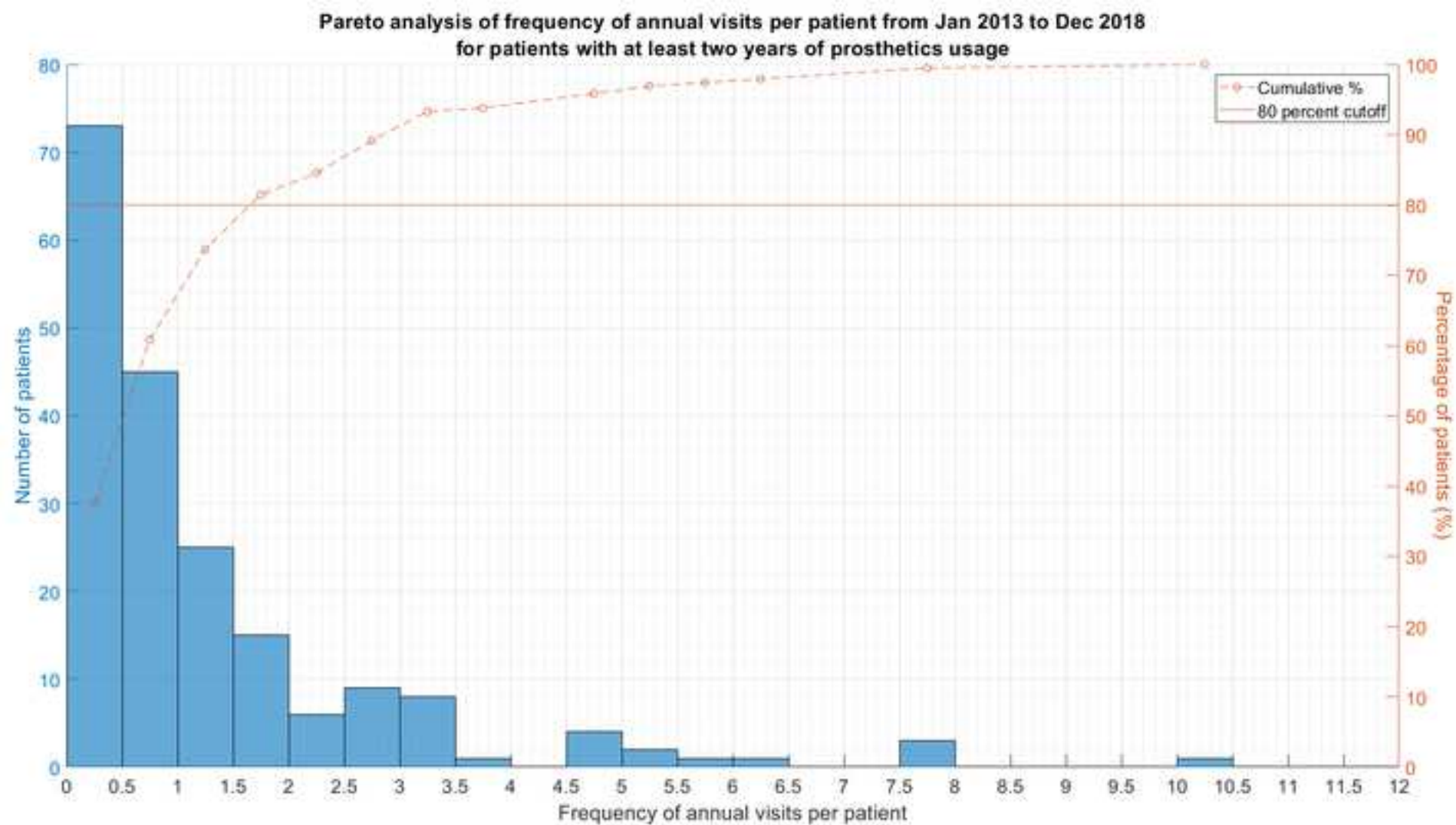
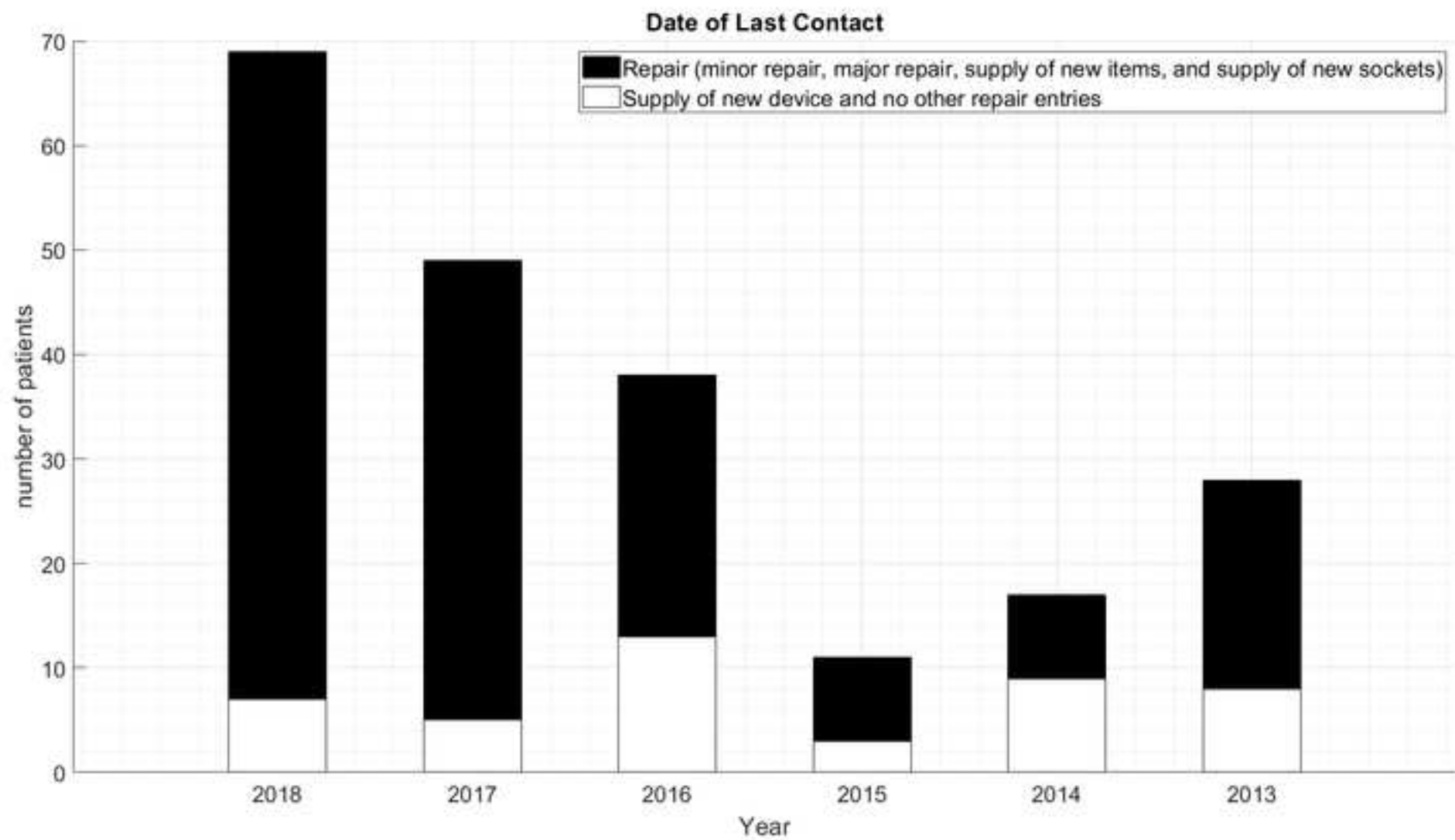
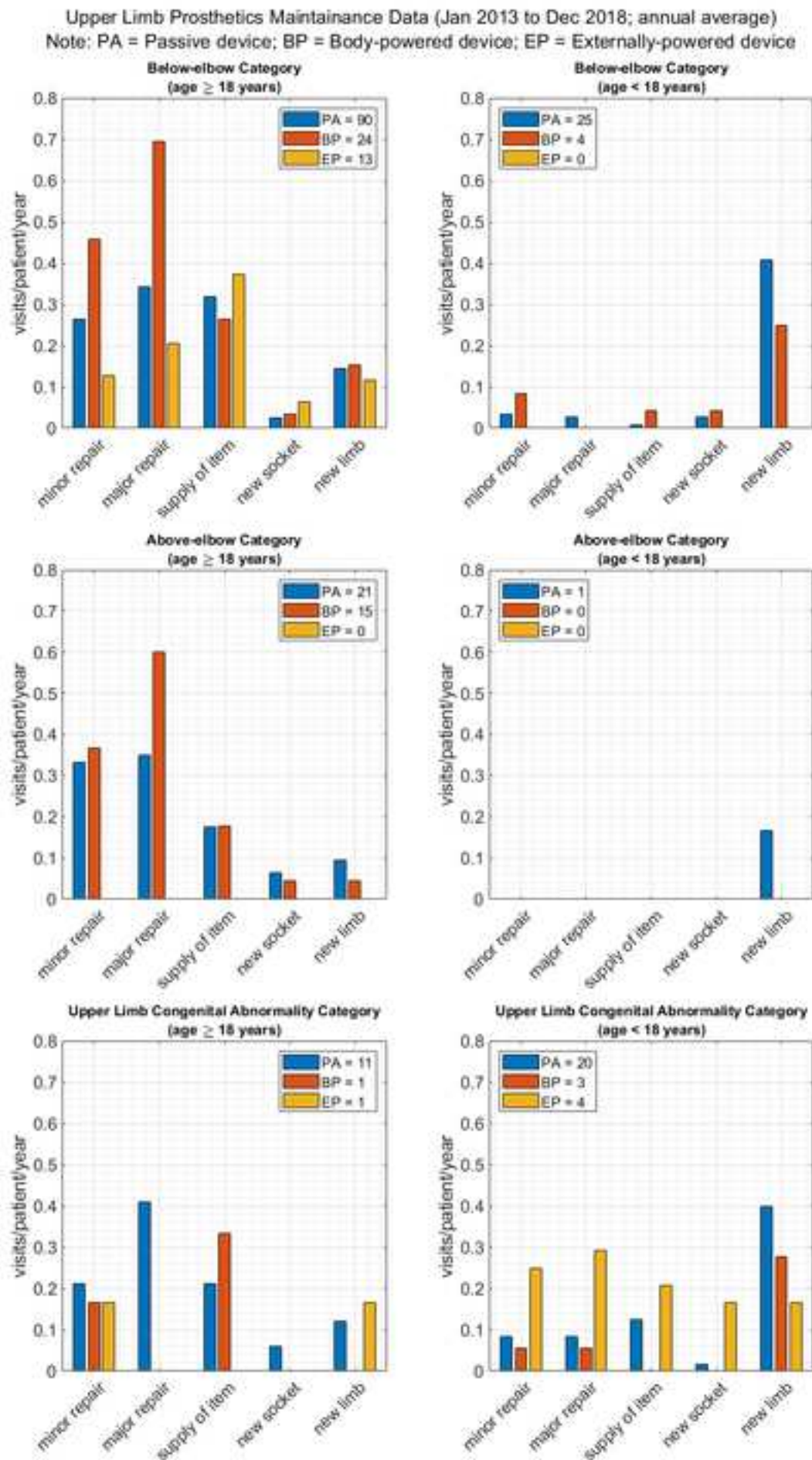


Figure 2







## Tables:

**Table 1.** Cause of upper limb loss/absence vs Patient age and Side of upper limb loss/absence

Category			Cause of upper limb loss/absence							Total
			Congenital	Trauma	Infection	Dysvascular	Neoplasia	Neurological	Unknown	
Age group	Above 18 Years	Male	19	27	9	4	2	0	30	91
		Female	29	13	5	4	3	1	20	75
		All	48	40	14	8	5	1	50	166
	Below 18 Years	Male	22	1	0	0	0	0	0	23
		Female	20	1	2	0	0	0	0	23
		All	42	2	2	0	0	0	0	46
Side of upper limb loss/absence	Unilateral Left	Male	27	13	4	2	1	0	13	60
		Female	28	6	2	1	0	0	10	47
		All	55	19	6	3	1	0	23	107
	Unilateral Right	Male	14	13	1	2	1	0	17	48
		Female	19	8	2	2	3	1	9	44
		All	33	21	3	4	4	1	26	92
	Bilateral	Male	0	2	4	0	0	0	0	6
		Female	2	0	3	1	0	0	1	7
		All	2	2	7	1	0	0	1	13
Overall		Male	41	28	9	4	2	0	30	114
		Female	49	14	7	4	3	1	20	98
		All	90	42	16	8	5	1	50	212

**Table 2.** Average frequency of visits to OCE by a patient per device per year (averaged over six years)

<b>Prosthetic device type</b>	<b>Category</b>	<b>Number of patients</b>	<b>Number of visits</b>	<b>Average frequency visits/device/year</b>
<i>Passive devices</i>	Male	82	433	0.88
	Female	86	515	1.00
	Total	168	948	0.94
<i>Body-powered devices</i>	Male	31	237	1.27
	Female	16	125	1.30
	Total	47	362	1.28
<i>Externally-powered devices</i>	Male	12	71	0.99
	Female	6	26	0.72
	Total	18	97	0.90



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