TOWARDS A UNIVERSAL COUPLER DESIGN FOR MODERN POWERED PROSTHESES

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INTRODUCTION

Universal coupler standards have played a critical role in allowing prosthetists to choose the best terminal device for their patient’s particular needs. The conventional quick-disconnect coupler allows users to passively rotate their prosthesis or to use a weak motorized rotator. However, the current standard precludes use of the strong motorized wrist rotators introduced by several companies and universities, as these devices would decouple the current universal coupler. A new universal coupler standard is required to allow interchangeability of these new devices. An open source universal coupler standard that meets necessary design requirements would better serve prosthesis users.

DESIGN REQUIREMENTS

We have identified the following eight major considerations that the design of an ideal universal coupler should meet in order to accommodate the needs of the prosthesis user and prosthetist:

1. Size constraints:
   a. Axial length should be 12 mm or less
   b. Outer diameter should be 25 mm or less

2. Ease of connection and disconnection:
   a. If multiple actions are required, they should be sequential
   b. Should allow prosthesis to be donned and doffed with cosmesis covering in place

3. Rotation constraint:
   a. Device should lock to prevent unwanted rotation
   b. Number of mechanical locking orientations should equal the number of permissible electrical connection orientations.

4. Strength constraint:
   a. Device should withstand 45 Nm of bending torque (70 Nm desired)
   b. Device should withstand up to 15 Nm of axial torque

5. Interface with adjacent segment:
   a. Adjacent segment may be larger than coupler diameter
   b. Contact with an adjacent segment larger than the coupler may increase connection strength

6. Manufacturing constraints:
   a. Proximal component may be a stand-alone part or made integral with a lamination collar
   b. Distal component may be a stand-alone part or made integral with the distal device
   c. May be manufactured from different metals depending on strength requirements of user

7. Location:
   a. May be used at the wrist
   b. May be placed near, but slightly distal to, the elbow for modular forearms

8. Electronic constraints:
   a. Male and female connectors for six conductors
   b. Should prohibit improper electrical connection
   c. Should preclude the possibility of electrode shorts during connection or disconnection

Size constraints

The size of the coupler is important for both user function and cosmetic appearance. Patients with long residual limbs will benefit from a coupler with a short axial profile, 12 mm or less, as it will not add significant length to the limb. The coupler diameter must be no larger than the minimum dimension of a small wrist, 25 mm, so that with a cosmesis covering, it will have the appearance of an anatomic wrist. The current conventional quick-disconnect coupler has a length of approximately 18 mm and a 40 mm diameter.

Ease of connection and disconnection

Connecting and disconnecting the coupler should require minimal dexterity so that it is manageable for all users, including bilateral amputees. For this reason, connecting and disconnecting the coupler should require as few user actions as possible, and if multiple actions are required, they should be sequential rather than simultaneous. Many cosmetic coverings extend from the hand to the elbow and would therefore prevent direct access to the coupler. The coupler must be easy to connect and disconnect without
visual feedback and without requiring removal of the cosmetic covering.

Rotation constraint
In order for the coupler to be fully functional, it must lock into position and not rotate passively in the presence of pronation or supination forces. The number of possible rotational positions for mechanical connection of the coupler should take into account the necessity of preventing incorrect electrical contact.

Strength constraint
We propose the coupler must withstand a minimum 45 Nm of bending torque and 15 Nm of axial torque based on previous studies of maximum torque in able-bodied persons [1]. However the desired coupler strength is 70 Nm in bending based on the maximum passive resistance in elbow designs [2]. Ideally, the coupler would be manufactured from a material strong enough for all users; however, various material grades may be required to meet the extreme force requirements of some users.

Interface with adjacent segment
For a proper anatomic appearance, it may be desirable for the segment just distal or proximal to the coupler to be larger than 25mm. Therefore, the coupler must not hinder a larger adjacent segment. In instances where the user’s adjacent body is larger than the coupler, the strength of the connection may increase.

Manufacturing constraints
The design of the coupler must allow it to be manufactured as an integral part of an adjacent segment such as a laminate forearm or terminal device, or as a stand-alone product that may be attached to an adjacent segment with screws or other means.

Location
Due to the variable location of amputation sites among users, as well as differences in design of current and future prostheses, the coupler should be capable of being located at any position along the length of the forearm.

Electronic constraints
Electrical power and communication signals must be able to pass through the coupler. Electrical connections must remain functional through frequent mechanical and electrical connection/disconnection cycles. The device must contain enough contacts for all necessary electrical communication: we have determined that six electrodes are sufficient for electrical power and communication needs. Careful design of the coupler is necessary to prevent improper electrical connections or electrical shorts during connection and disconnection. Furthermore, when coupled the coupler design should prevent or limit exposure of electrical connections to moisture.

CONCEPTS

The three universal coupler concepts presented herein illustrate possible mechanical and electrical features that have been developed to address these eight design considerations. These designs were independently developed, yet all three have striking similarities. Each concept uses multiple tabs to transfer forces across the two components and engagement of the coupler requires a sequential translation followed by rotation.

Concept 1
Concept 1 (Figure 1) has an axial length of 10 mm and a 25 mm diameter. The main features of the proximal (light tan) and distal (dark teal) components are shown in Figure 2. Component assembly is shown in Figure 3.

Figure 1: Universal Coupler, Concept 1

Care has been taken to ensure that these components may be assembled without getting hung-up during assembly. As the two components are brought together, the chamfered edge (E, Figure 2) guides the male shaft of the distal component (D, Figure 2) into the hollow center of the proximal component.
Figure 2: Features of Universal Coupler, Concept 1. The proximal component is shown on the left (light tan), and the distal component on the right (dark teal).

The proximal and distal components slide together for 5 mm until the transverse pin (B, Figure 2) on the distal component contacts the male shaft (Figure 3b). The distal component must then be rotated until the keyed shaft (F, Figure 2) is aligned with the transverse pin. This feature creates one unique orientation for coupler assembly. Once the transverse pin and keyed shaft are aligned, the distal component translates another 5 mm until the outer rims of both components make contact (Figure 3c). Three large tabs (A, Figure 2) provide strength and resistance to bending. Locking the coupler requires a 60° rotation of the distal connector (Figure 3d). The locking switch and electronic contacts have been omitted from these figures.

Figure 3: Assembly of Universal Coupler, Concept 1: (a) Unassembled, (b) Partial assembly, (c) Full assembly, (d) Full assembly after lock. Distal component is shown in dark teal, proximal component in light tan.

Concept 2

Concept 2 (Figure 4) has an axial length of 9.5 mm and a 25 mm diameter. It is based around an auto-locking system and is composed of four components. The proximal component (black) and the distal component (green) form the structure of the wrist, with the latch (red) and return spring (silver) providing the locking mechanism (Figure 5).

Figure 4: Universal Coupler, Concept 2

Figure 5: Individual Components of Concept 2: (A) distal component (green), (B) latch (red), (C) proximal component (black), (D) return spring (silver)

As the distal and proximal units come into contact, chamfered edges (B, Figure 6; Figure 7A) align the tri-leaflet pattern (D, Figure 6) to its corresponding cavity (C, Figure 6) and initiate the depression of the latch.
Figure 6: Features of the Universal Coupler, Concept 2. The distal component is shown on the left (red & green) and the proximal component on the right (black).

As the distal unit is inserted, the leaflets continue to depress the latch; once this reaches a maximum axial depth of 3 mm within the proximal unit (E, Figure 6; Figure 7B), it is rotated counter-clockwise by 60 degrees by which time the leaflets are fully engaged within their corresponding cavities (A, Figure 6; Figure 7C). At this point, the latch is returned to its resting location by the stored potential within the return spring; thereby fully enclosing the leaflets and completing the locking process (Figure 7D). To disengage the connector the latch is manually displaced by the user re-exposing the leaflets in a clockwise rotation disengagement process.

Concept 3

Concept 3 (Figure 8) has an axial length of 10 mm and a 25 mm diameter. An important feature is room in the center for mounting two circuit boards, a distal board with male connectors and a proximal board for these to contact. The distal board mounts twenty-one gold plated pogo stick contacts, four for each of five conductor paths and a sixth single pogo stick in the center for the sixth path. Each pogo stick is rated to carry 2A. Thus, the five outer paths can carry 8A continuously. Typically, only two paths need to carry high current, and some of the pogo sticks can be omitted. During coupling of the two components, the sticks compress against gold plated bands on the other board, and then slide along the bands as the two elements of the coupling rotate 30° to their locking position.

Figure 7: Assembly of Universal Coupler, Concept 2: (A) Unassembled, (B) Inserted but not engaged, (C) Engaged but not locked, (D) Full assembly with latch engaged.

Figure 8: Universal Coupler, Concept 3. The complete concept 3 coupler is aligned for assembly. The pogo stick contacts are visible as are the five conducting rings on the proximal circuit board. The spring loaded lock ring is shown in the position it attains after the two halves are pushed together.

Figure 9: Assembled Universal Coupler, Concept 3. When the two halves in Figure 8 are pushed together and rotated 30°, the lock ring (orange) snaps into the position shown by the wing exposed on the left, preventing rotation. To uncouple, the user lifts (distal-direction) on the two locking ring wings and rotates 30° to the unlock orientation.
At present, the parts of concept 3 exist as a CAD model. This makes changes easy. For instance, there are six engagement elements on each coupling. If every element is 30° wide, there is a lock position every 60°. Perhaps users would prefer eight lock positions spaced at 45°. The circuit boards shown permit coupling at multiple rotational positions.

Figure 10: Section View When Locked, Concept 3. The tabs are not exactly 30°, which guarantees only one possible lock orientation. Making all angles 30° would allow six locking orientations. The three cavities shown are for springs that cause the ring to snap into the lock position just as the halves are rotated into alignment.

The universal coupler will seldom be used with devices that are only 25 mm in diameter. More typically, the coupler will join a size 7.75 hand to a fixed or a powered wrist. For cosmetic reasons, a two degree of freedom powered wrist should be oval where it connects to the hand and circular where it connects to the forearm, thereby maintaining a circular profile during axial rotation. Axial rotation would occur proximally between the wrist and forearm, while flexion-extension takes place in the wrist. This permits use of a coupler between the axial rotator and wrist with multiple locking positions.

An oval version of concept 3 is worth examining, because it illustrates the problems with scaling up the connections with the proximal and distal elements while always keeping all versions of the coupling interchangeable. As shown in Figure 11, there is a cavity between the two halves. Some of this cavity can be eliminated to make the lamination collar shorter.

Figure 11: Oval Outer Profile, Locked, Concept 3. This section view show the lamination collar along with the distal oval element, which may be made integral with the hand chassis. The oval measures 44mm by 54mm and would be suitable for use with a size 7.75 hand.

Figure 12: Oval Outer Profile, Unlocked, Concept 3. Note the need for slots to permit rotating the wings during lock and unlock.

CONCLUSION

There is a functional need for an improved universal coupler standard to meet the needs of patients using modern powered prosthetics. A standard adopted by the industry should allow the maximum function for the patient and the greatest compatibility between various prosthetic designs. The design requirements presented here outline what we believe would maximize function of a universal coupler. The three concepts show ways in which these design requirements may be met. The focus of these three concepts has been to show ways the mechanical aspects of a coupler design will meet the design criteria. Future work will include robust electrical connector features and minimizing how much moisture may get to the electrical connections. Furthermore, aspects of these three concepts may be combined to provide a single design with optimal function for the user.

References
