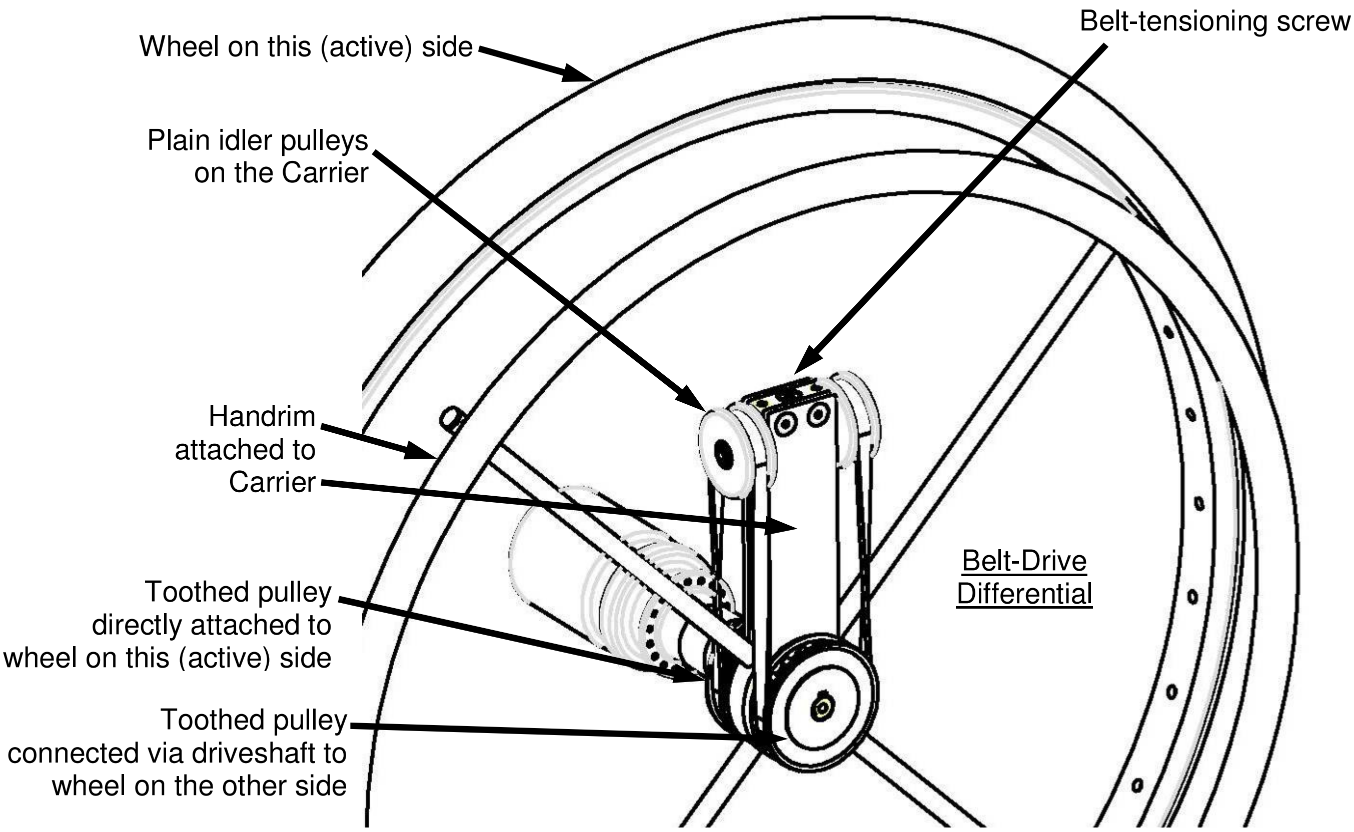
The Neater Uni-Chair – An Engineer's* Perspective

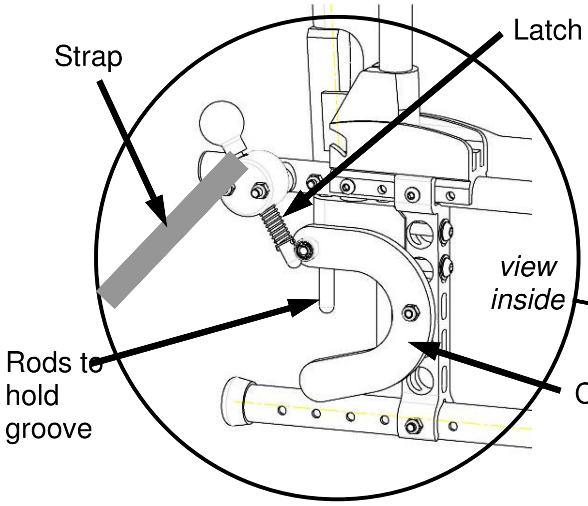
In 2006/7 I was approached by Samuel Lesley (formerly of the University of Cambridge department of Engineering) and Dr Anne Mandy (Healthcare Researcher at the University of Brighton) to develop a one-arm drive wheelchair for people with hemiplegia. Conventional dual-handrim wheelchairs and pull-push lever wheelchairs were performing badly and are impractical. Electric wheelchairs were not suitable for many users in many environments and did not meet therapeutic needs.

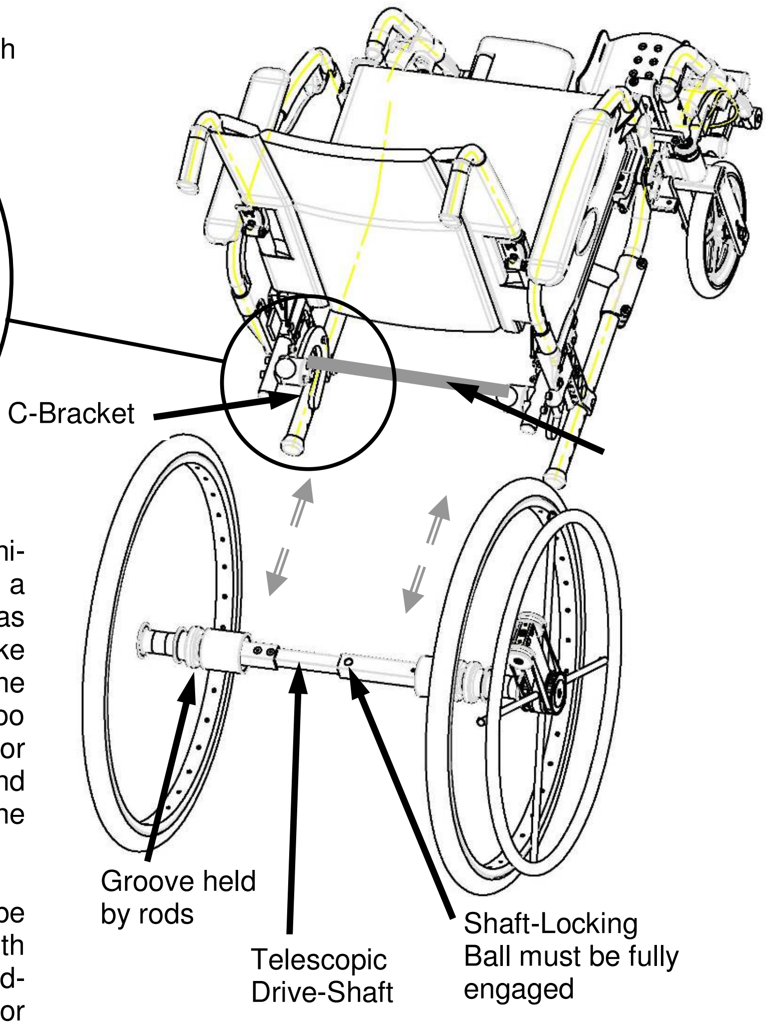
Along with a former student, Samuel Lesley had developed a prototype one-arm drive wheelchair with foot-steering and a differential drive to allow cornering. The foot-steering mechanism used a toothed-belt drive that could not be folded out of the way to allow easy access to the chair and the axis of movement required by the user was not ideal. The epicyclic gear differential was very expensive to produce and used a heavy telescopic driveshaft that was difficult to assemble. There were also issues of strength, reliability and manufacturing cost.

My first task was to come up with a differential mechanism that would be reliable, efficient, compact and cheap enough to produce. A differential transmits input torque (in this case from the handrim) to two outputs (the wheels) in a way that allows the outputs to rotate automatically at different speeds (such as when going round a tight bend); the average speed of the two outputs is the same as the input. Epicyclic differential components are expensive as are bevel gears which would also not be very compact. I thought up a way of making a differential just using overlapping spur gears; a model proved it would work but it would still have been a little expensive and not at all compact. Part of a differential requires a change in direction within the mechanism (if the drive input is stationary, turning one output wheel one way makes the other output wheel turn the opposite way – the average then is zero). In a belt drive, one usually considers input and output directions to be the same. My "Eureka moment" came late one night when I realised that a belt could be folded over to change the direction of rotation between input and output.



The resulting differential mechanism is very simple, requiring just two toothed pulleys (one for each wheel) and two plain idler pulleys on a carrier turned by the handrim. The toothed belt used is reinforced with steel wires for strength and to avoid stretch and creep. It should not require re-tensioning after initial bedding-in. The tooth-form is low backlash with the teeth smaller than the gaps between them on the aluminium pulleys and vice versa on the plastic part of the belt – thus maximising the strength to size ratio. Pulley and belt dimensions are kept compact but strong enough for a burly 75kg man to “pull a wheelie” using the one-arm drive handrim! (Torque was measured using an electronic strain gauge). This is over-engineered for normal use but years’ of experience in this field leads me to design with potential abuse of the equipment in mind. The large diameter of the wheels allows enough distance between the toothed pulleys and the idler pulleys for the belt to be twisted without risk of it riding off the pulleys. The mechanism is very low friction – under no-load it can be turned easily with a little finger.



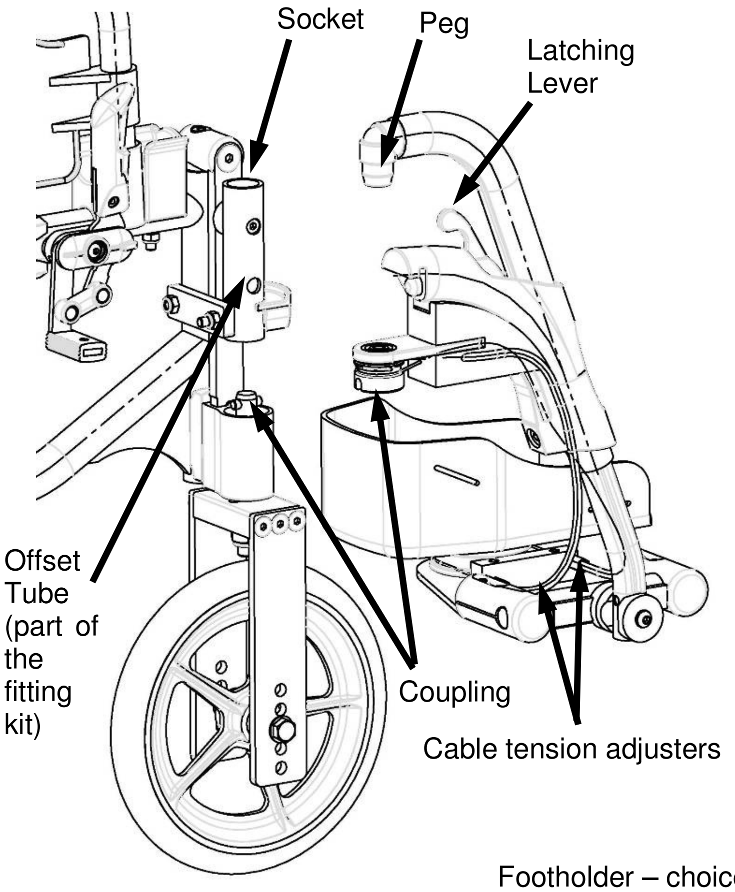


Detachable Wheels and Shaft Assembly

Many carers of people using the Neater Uni-Chair may themselves be unable to lift a heavy wheelchair into a car boot. It was important to make it easy for them to take the chair apart – ideally removing the wheels without having to crouch down too far. I developed a quick-release system for the whole sub-assembly of both wheels and the driveshaft. The wheels just slide off the driveshaft once disengaged from the chair.

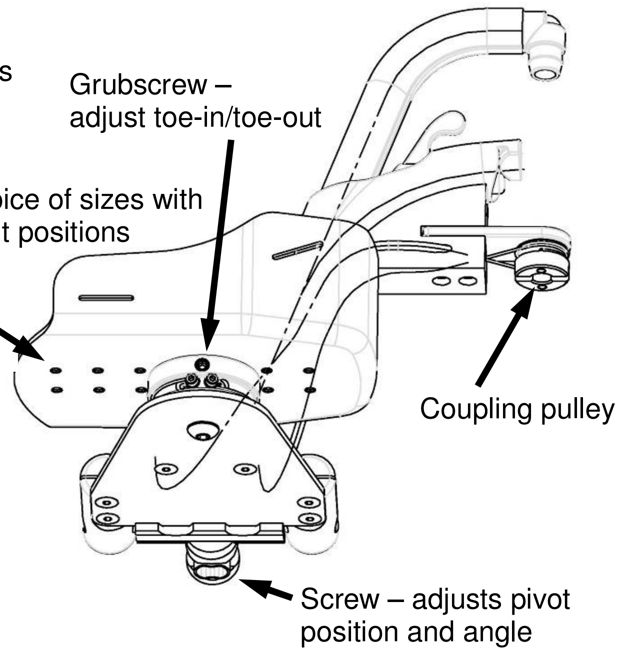
Alternatively, the drive-shaft can be removed and the wheelchair folded flat with the wheels in place. The driveshaft is hard-black-anodised ptfe coated aluminium for hard wearing and smooth assembly. The locking ball is large for easy disengagement.

The initial design brief called for a disengageable steering mechanism. Many mechanisms were explored and finally a unit was developed using spring loading to disengage the steering when the user lifted their foot. Success in the laboratory was not repeated in trials in users' homes however as they became confused especially when trying to disengage and re-engage the steering when moving into reverse. It was therefore decided to make keep the steering engaged at all times. This proved very successful in trials with the user able to go straight into reverse without thinking. It also allowed (indeed it required) the steered wheel to turn with virtually no castoring effect – requiring far less effort to steer even when going very slowly. Concerns that a carer may struggle to steer the chair when pushing it proved inconsequential. Users expressed a preference to have control over steering when pushed and the lack of castoring was beneficial when negotiating cambers.



Steering Footrest Assembly

The final design uses a cable linkage to allow easy adjustment of the foot-holder position and pivot axis. The cables are strong and flexible 7x19 strand stainless steel with plastic coating for reduced friction, wear resistance and ease of trimming without fraying. They are held in the hard-black-anodised ptfe coated coupling pulley with grubscrews and ball bearings to avoid damage. With experimentation, we arrived at an optimum ratio for the diameters of the pulley under the footrest and the coupling pulley of 2.5 to 1. This enables very sharp turns. (It is possible to pivot around one stationary rear wheel). The cables are offset vertically at the coupling so they do not rub each other.



The steering footrest assembly can be fitted, swung out of the way for ease of entry to the chair and detached in the same way as the conventional footrest.

The Neater Uni-Chair is currently an adaptation of an Invacare Action 3 (or Action 3 NG). This chair was chosen following consultation with several wheelchair services in the UK. It is available as a kit with detailed instructions for bolt-on fitting by wheelchair technicians. Alternatively, we can provide the complete chair. With funding, it would be possible to develop the kit to fit other wheelchairs.

Part of the development involved load and fatigue testing at the MHRA as well as crash testing. (Though having now seen high speed crash-test dummy video footage, I would not recommend travelling in any wheelchair without a headrest). If anything, the Neater Uni-Chair is stronger than the standard Action 3 chair due to the rigidity of the drive shaft. Heavy duty wheels are used to compensate for the loss of strength from removal of the standard handrims.

The Neater Uni-Chair has performed very well in laboratory tests where typically, users complete a course in half the time compared to using a dual-handrim chair whilst working at the same rate (oxygen rate of consumption and heart rate). Pressure mapping has shown much more even posture than with other types of one-arm drive chair. High tone has not been a problem. Users have learned quickly and easily how to steer and drive the chair. Home trials have been successful. (Details of clinical research papers can be found at www.neater.co.uk)

The aesthetics of equipment are important. (Not the top priority though - I have come across designs where form and aesthetics have overridden function and engineering considerations). I was once told that a photograph of the Neater Uni-Chair that I had sent for publication must have been of an un-adapted chair – the adaptations blend in sufficiently well to the look of the chair that they are often not noticed.

Patents applied for

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