Prospects for Complete Restoration of Bladder Function by Neuroprostheses

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Bladder dysfunction in spinal cord injury

Supra-sacral lesions to the spinal cord nearly always lead to serious disruption of lower urinary tract function: impairment of voluntary sphincter control and sensation of bladder fullness, aberrant reflexes of the bladder and an uncoordinated urinary sphincter [1]. As a consequence, bladder emptying is impaired and the result is reflex incontinence. Reflex incontinence is primarily caused by detrusor hyperreflexia, an aberrant reflex that emerges after a period of spinal shock following SCI (Figure 1). It is often associated with dyssynergic contractions of the striated sphincter muscle of the urethra, preventing efficient emptying of the bladder. Persons with SCI frequently develop large residual volumes and urinary tract infections, and are prone to upper urinary tract damage and subsequent renal failure if managed incorrectly.

![Diagram](image)

Figure 1. The neurogenic bladder in supra-sacral spinal cord injury. (a) Aberrant pelvic reflexes causing detrusor hyperreflexia and detrusor external sphincter dyssynergia. (b) Traces showing the high bladder pressures generated, dyssynergia of the sphincter, associated EMG and urine leakage during videourodynamics. (c) X-ray image shows the bladder and sphincter at the exact time of dyssynergia.

Medical treatment is usually by a combination of drugs for suppressing detrusor hyperreflexia and intermittent catheterization for emptying the bladder. However, the antimuscarinic drugs used to treat incontinence often have debilitating side effects, such as constipation, dry mouth, and visual disturbance. Emptying the bladder can also be very troublesome, especially in women for whom no reliable collection device exists (other than indwelling catheters and bags or ungainly pads), and intermittent catheterization can often introduce bladder infections. Other more radical approaches such as surgery for augmenting the bladder, sphincterotomies, cutting posterior sacral roots to suppress hyperreflexia or repeated injections of toxins such as *Botulinum* toxin to paralyse the sphincter and bladder may all have destructive effects which could preclude the use of future developments including more novel implantable neurostimulating devices.
Neuroprostheses for emptying the bladder and controlling incontinence

During the past 20 years two key developments using implantable neural prostheses have had a significant impact on treating and managing patients with a neurogenic bladder. The first of these was the Brindley sacral anterior root stimulator, originally developed in the 1970’s for bladder emptying in spinal cord injury but later combined with cutting of the sacral sensory nerves (posterior rhizotomy) to prevent incontinence [2]. The second was the sacral nerve stimulator developed by Tanagho and Schmidt [3] for suppressing detrusor hyperreflexia and incontinence, not by cutting nerve roots but by neuromodulation with electrical stimulation of the same sacral sensory nerves.

These two techniques, among others, are now being combined using to restore more complete control of the dysfunctional bladder in people with a supra-sacral spinal cord injury [4] but without destroying nerves.

Six areas of development will be discussed:

- Sacral Anterior Root Stimulation for emptying the paralysed bladder
- Sacral nerve stimulation for suppressing detrusor hyperreflexia
- Conditional neuromodulation for automatic control of reflex incontinence
- The Sacral Posterior and Anterior Root Stimulator Implant (SPARSI) [5]
- Selective stimulation of sacral roots to prevent detrusor-sphincter dyssynergia

Ultimately, it is hoped that by combining conditional neuromodulation for reflex incontinence with selective neurostimulation for bladder emptying we can completely control the neurogenic bladder without cutting any sacral sensory nerves (Figure 2).

![Diagram of neuroprostheses](image)

**Figure 2.** Combining various neuroprosthetic techniques to give complete control of the

The big challenge will probably be to overcome the detrusor-sphincter dyssynergia resulting from the emergence of aberrant reflexes following spinal injury. By preserving all pelvic reflexes, including those for erection, ejaculation and bowel control, as well as those essential to guard against stress incontinence, we will help to reassure people with a spinal cord injury that this technology will improve their quality of life until the time comes when neural repair becomes a realistic possibility for them.
This presentation briefly reviews some future possibilities for combining existing and emerging science and technologies [6], [7] develop an implantable neuroprosthesis capable of restoring complete control to the bladder and sphincters in spinal cord injury.

References: