Committee 11 D

Surgery for the Neuropathic Patient

Chairman

D. Castro-Diaz (Spain),

Members

D. Barrett (USA),

P. Grise (France),

I. Perkash USA),

M. Stöhrer (germany),

A. Stone (USA),

P. Vale (Portugal)

Consultants

H. Madersbacher (Austria),

A. Mundy

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H. Madersbacher, A. Mundy

INTRODUCTION

Incontinence is commonly associated with (a condition which may be secondary to) several types of neurological disease or injury. The neurological problem may primarily affect the sphincter, the detrusor, or both the sphincter and the detrusor. Surgery may correct the incontinence in many patients but is usually indicated only after all conservative therapies have been attempted and failed or have proved to be ineffective. In many cases, lessons learned from this conservative therapy, such as intermittent catheterisation, may enhance the changes achieved by surgery, allowing the patient to become more socially flexible and further improve quality of life.

As with all surgery on the urinary tract, certain principals must be adhered to in establishing the appropriateness of any procedure. These are: 1) preservation of renal function and 2) control of incontinence. In addition, for patients with neuropathic bladder, other issues need to be considered, namely:1) social circumstances, 2) degree of disability, 3) cost effectiveness, 4) technical difficulty and 5) complications.

The following chapter is a critical overview of the surgical procedures available to manage the various forms of neuropathic bladder.

A. FAILURE TO EMPTY

I. SURGERY TO ENHANCE DETRUSOR CONTRACTILITY

Restoration of the bladder's reservoir function in combination with the ability for complete voluntary evacuation has been the aim of the urinary bladder stimulation over the past decades. Various approaches have been reported to protect the upper urinary tracts and to prevent urinary incontinence in neurogenic bladder dysfunction.

A variety of implants have been used in patients with spinal cord injury or disease, with electrodes on the bladder wall, the splanchnic pelvic nerves, the conus medularis, the mixed sacral nerve or the sacral anterior roots.

Direct bladder stimulation has produced poor results and has been abandoned. Splanchnic pelvic nerves stimulation has also been abandoned due to a difficulties encountered with surgical access and because these nerves also include sympathetic fibers to the bladder neck and afferent fibers. Stimulation at the conus medularis level has been reported, with electrodes implanted directly into the gray matter in this section of the cord. Results have only been reported in one publication and the authors abandoned this work more than 15 years ago [1 - 2].

Intravesical electrical stimulation has been proposed as a method to improve the bladder function in conditions with weak detrusor contractility. The method is based on activation of the bladder mechanoreceptors, which initiate the normal micturition reflex. The results seem encouraging specially if there is residual detrusor contractility [3]. (Refer to chapter on Conservative Therapy for details)

1. Sacral anterior root stimulation to control detrusor contraction

Brindley, in London, started animal experiments in order to develop a system for intradural sacral anterior root stimulation in the 70's. The first successful sacral anterior root stimulator in a human subject with traumatic paraplegia, was implanted in 1978 [4]. Since then more than 3000 patients have been implanted worldwide. The technique of intradural sacral anterior root stimulation consists of the combination of complete posterior rhizotomies (S2, S3, S4) and simultaneous implantation of the Finetech-Brindley electrodes on the intact anterior roots. Posterior rhizotomy promotes detrusor arreflexia and normal compliance, thus avoiding reflex incontinence. With this technique more than 80% of the patients were able to achieve sufficient intravesical pressure to produce efficient voiding. Several attempts, since then, have been made to improve this technique. The principal purpose of the Finetech-Brindley bladder controller is to achieve bladder emptying. Stimulation of the anterior sacral roots, mainly S3 and S4, results in bladder contraction with simultaneous activation of the urethral sphincter and pelvic floor. The nerve roots contain a mixed population of somatic fibers innervating leg musculature, pelvic floor muscles, urethral and anal sphincters and pre-ganglionic parasympathetic fibers innervating the detrusor muscle. The somatic nerve fibers supplying the urethral sphincter have a larger calibre than the parasympathetic fibers; since large diameter fibers need a lesser stimulus for activation than the smaller ones, activation of the smaller diameter fibers is always accompanied by activation of the larger ones. The result is simultaneous activation of the detrusor and the urethral closure mechanism. The striated muscle of the sphincter relaxes more rapidly than the smooth muscle of the detrusor, which continues to contract after the cessation of the stimulation. Intermittent stimulation with bursts of impulses produces a rapid contraction of the urethral sphincter and a slow but more sustained contraction of the detrusor. Micturition occurs during the gap at the end of each burst of impulses, whilst the bladder is still contracted with the urethra relaxed (Figures 1-6). Electrical micturition occurs at physiologic pressures in 4 to 8 spurts, within one minute in most patients. The bladder then remains arreflexic until the next micturition sequence [5, 6, 7, 8] *LEVEL OF EVIDENCE 4.*

Several additional methods have been investigated to obtain a more physiological voiding pattern. These include surgical interruption of the somatic fibers, blockage of pudendal nerve transmission, fatiguing of the urethral sphincter, and selective small fiber activation. Some work has been done on the selective activation of the small diameter parasympathetic fibers on the anterior sacral nerve roots, using a selective anodal block. The principle of this technique is based on the observation that close to an anodal contact, the propagation of an action potential can be blocked by hyperpolarization of the fiber membrane. If the membrane is sufficiently hyperpolarized, action potentials cannot pass this zone and are wiped out. As large diameters fibers need a smaller stimulus for blocking than do the smaller fibers, a selective blockage of the large fibers is possible. Thus, selective small fibers activation can be obtained by a combination of excitation of both large and small diameter fibers and by blockage distal to the excitation point of the propagation of the induced action potentials in the larger fibers. This can be achieved with rectangular pulses or by the application of multichannel-generated quasitrapesoidal pulses in an anodal block stimulation technique. These studies have shown feasibility in animals but have not been applied to human subjects [9].

More recently attempts have been made to avoid the posterior rhizotomy, and obtain the same result, using selective urethral sphincter blockade and reversible deafferentation using cryotherapy. If these results can be reproduced in chronic trials and during intra operative evaluation, this technique may play some role in clinical practice [10].

Another technique recently described by Craggs et al is that of combining sacral anterior root stimulation for electromicturition with electrostimulation of the posterior sacral roots to suppress the neurogenic detrusor overactivity (SPARSI). Thus also achieving efficient emptying avoiding the rhizotomy.

2. Muscle augmentation to increase bladder contractility

Though neurostimulation, especially of the anterior sacral roots, is effective in inducing contraction in spinal cord lesions above the sacral micturition centre, it has no role to play in the flaccid neurogenic bladder due to lesions at or below the sacral micturition centre. The treatment of choice for detrusor underactivity is clean intermittent catheterisation. However, in an attempt to eliminate catheter related morbidity and improve quality of life for patients with acontractil detrusor, the restoration of bladder contractility may be desirable. The use of a striated muscle flap that can be electrically stimulated, to augment bladder contractility, is an attractive idea. Some authors have evaluated the use of the latissimus dorsi muscle wrapped around an artificial reservoir or wrapped around the acontractil bladder, after division of its motor supply and its reanastomosis to an active nerve [11, 12, 13] Others have tried to use the rectus abdominus because of its proximity to the urinary bladder [14].

A pedicled latissimus dorsi muscle flap has been used as a myocardial substitute in patients with heart failure due to cardiomyopathy. Latissimus dorsi bladder myoplasty is more challenging and more complex. It involves latissimus transposition with microsurgical anastomosis of its blood supply as well as its innervation in order to be placed in the pelvis. This revascularization and reinnervation, though challenging, is achievable. It has been shown that the latissimus dorsi wrapped around the bladder is able to generate enough intravesical pressure to promote voiding. Although initial experience is promising [15, 16] more studies are needed in order to confirm the clinical applicability of these techniques.

Figure 1 : Sacral Posterior Root Rhizotomy and Sacral Anterior Root Stimulation with the Brindley Device.

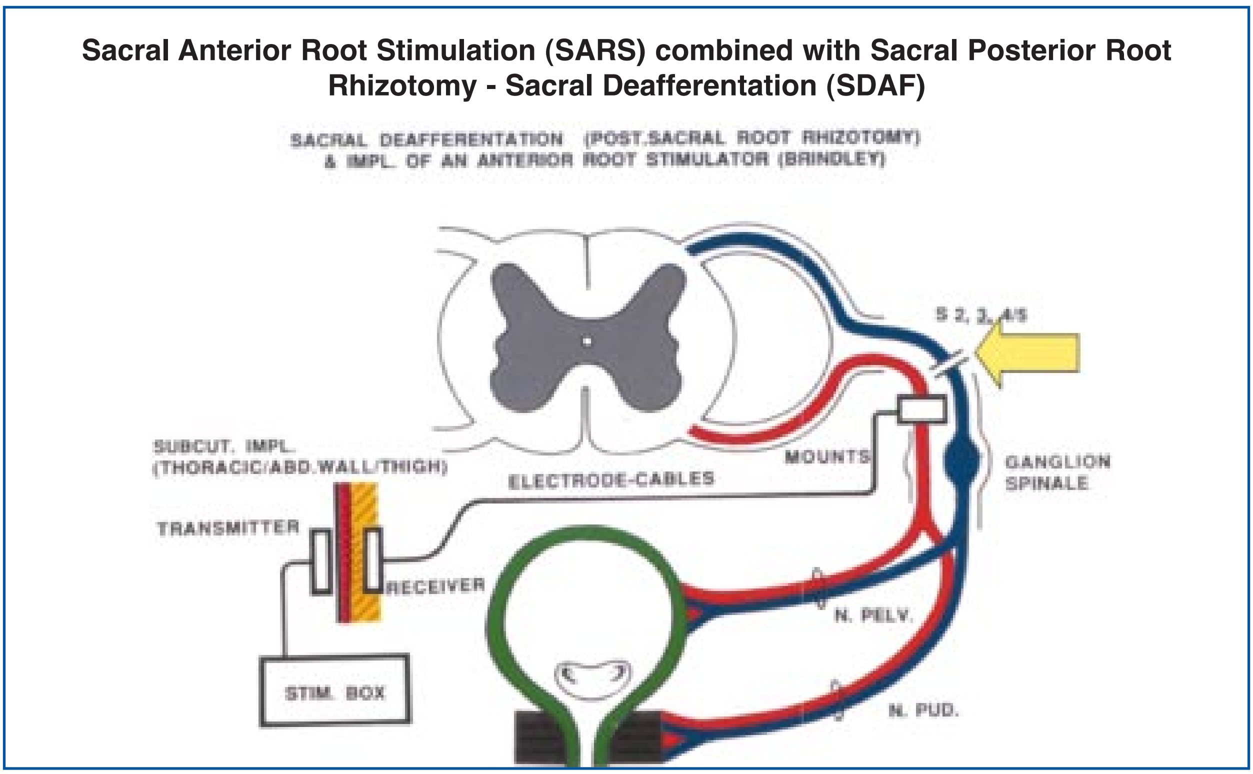


Figure 2 : Sacral Posterior Root Rhizotomy and Sacral Anterior Root Stimulation with the Brindley Device.

Figure 3 : Sacral Posterior Root Rhizotomy and Sacral Anterior Root Stimulation with the Brindley Device.

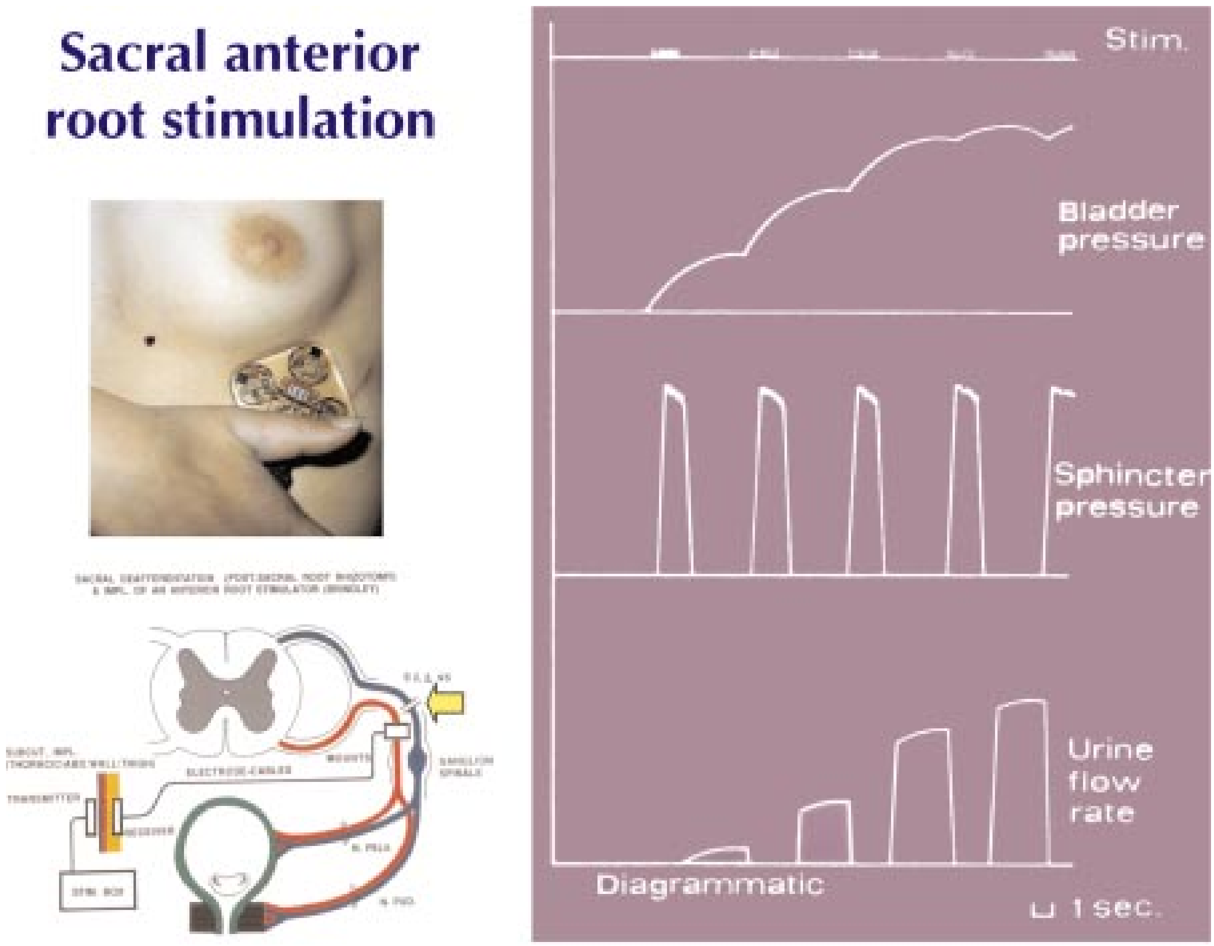
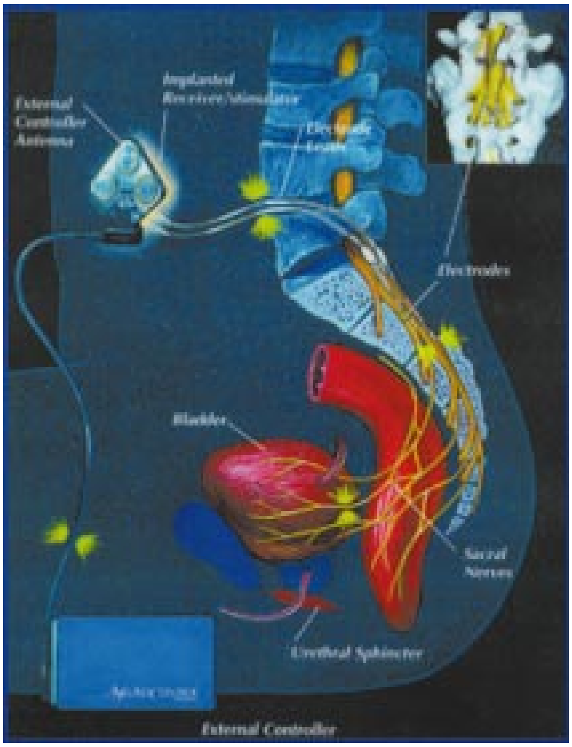


Figure 4 : Sacral Posterior Root Rhizotomy and Sacral Anterior Root Stimulation with the Brindley Device.

Electrostimulation Sacral Anterior Root Stimulation (SARS)



Prerequisite:
suprasacral lesion with intact efferent neurons and a detrusor able to contract

Technique:

- SARS to stimulate bladder contraction
- SDAF to abolish reflex voiding

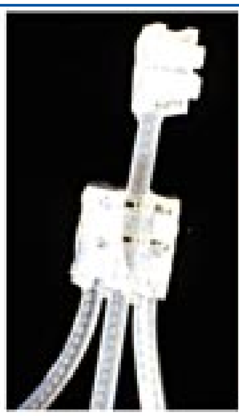
Advantage: efficient voiding continence

Disadvantage: loss of reflex erections

Figure 5 : Sacral Posterior Root Rhizotomy and Sacral Anterior Root Stimulation with the Brindley Device.

Placement of the electrodes

intradurally



extradurally

Figure 6 : Sacral Posterior Root Rhizotomy and Sacral Anterior Root Stimulation with the Brindley Device.

II. SURGERY TO DECREASE OUTLET RESISTANCE

1. SPHINCTEROTOMY

Transurethral incision of the external urinary sphincter (TUIS) is a reasonable option to promote bladder emptying and prevent urologic complications in the male spinal cord injured patient (or myelopathic disorders in male).

This procedure helps to decrease urinary outlet resistance due to detrusor-sphincter dyssynergia (DSN). The goal is to reduce the intravesical voiding pressure mediated by detrusor contractions against a dyssynergically contracted external urethral sphincter. The primary indication for sphincterotomy is in those individuals who have elevated residual urine volumes in the presence of good but involuntary detrusor contraction and who have failed conservative management. Other indications are repeated episodes of autonomic dysreflexia (17, 18) typically in a tetraplegic patient with poor hand function, whose bladder drainage through intermittent catheterisation (IC) is cumbersome and difficult to maintain 24 hours/day, repeated urinary tract infections, difficult catheterisations due to urethral false passages (19), and/or secondary bladder neck obstruction due to a "ledge" formation [20]. Inadequate bladder drainage resulting in upper tract changes, reduction of renal function, vesico-ureteric reflux, stone disease and prostate-ejaculatory reflux, with associated epididymo-orchitis, may also be considered for TUIS.

The goals of sphincterotomy are: stabilization or improvement in renal function, prevention of urosepsis, lowering the detrusor leak point pressure, stabilization or elimination of vesicoureteric reflux and eliminating the need for chronic indwelling catheterisation. Following successful sphincterotomy, improvement in bladder emptying and stabilization of the upper urinary tract function can be reasonably expected in 70-90% of patients (21).

Transurethral external sphincterotomy can be performed with either a knife electrode or using a resection loop at the 12 o'clock position [22]. Following electrosurgical TUIS significant intraoperative and postoperative bleeding may occur with subsequent clot retention requiring prolonged drainage with a large diameter catheter. In addition, urethral strictures, impotence and need for reoperation have been reported in 30 to 60% [23], [24] of patients. In some initial TUIS failures an additional bladder neck incision or a TURP is required [24]. Other failures reported are due to inadequate surgery, post TUIS bulbous urethral strictures and poor detrusor contractility. In order to improve these shincterotomy results using both contact and beam lasers have been applied through standard cystoscopes [25]. The laser energy is delivered fiberoptically either through a reusable contact laser probe screwed on to the tip of a rigid fiber or through the direct contact of fiber for the delivery of the Holmium laser (Figure 7). Free beam laser leads to coagulative necrosis, and therefore is not suitable for TUIS. Sphincterotomy with contact

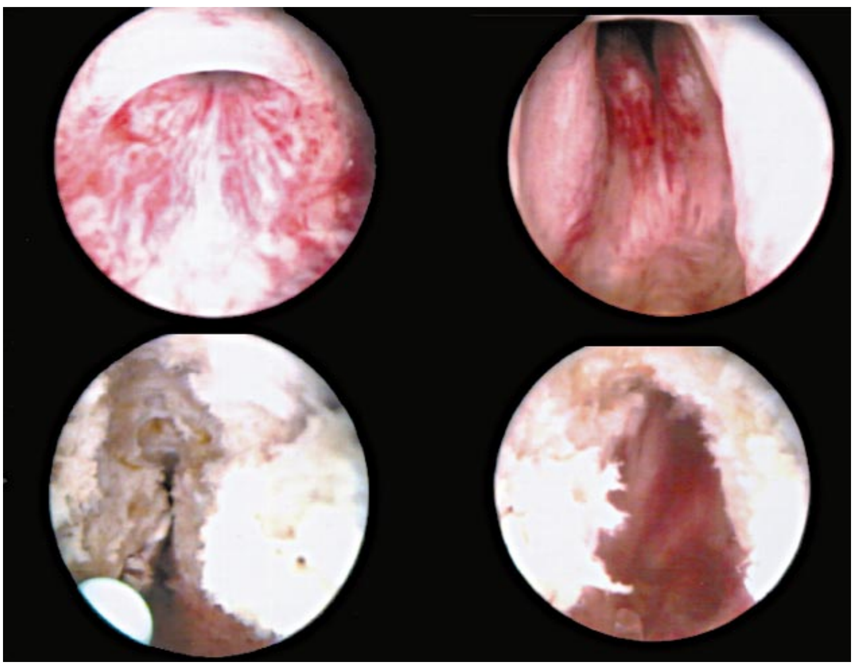


Figure 7 : Sphinterotomy with Holmium laser incision at 0´clock position

laser requires repeated passes to cut and vaporize all urethral tissue, stopped just short of the spongiosum to prevent perforation of the urethra [24, 25]. Results following the use of contact laser have been encouraging with significantly reduced incidence of operative and perioperative bleeding and reduced need for repeat sphincterotomy: 7% to 15% versus over 30% in reported series following conventional electrocautery TUIS [24, 25]. Detrusor leak point pressure below 40 cm water seems to be a useful urodynamic parameter for the successful outcome of TUIS [23 26].

Following TUIS, some patients may have difficulty keeping the external condom in place. Although such patients have been helped in the past by placement of a semi rigid penile implant [27 28], the incidence of infection, erosion and implant failure in this patient population has been significant compared to non paralyzed patients. Thus this procedure is now reserved for a very selected group. With adequate control of urinary tract infection, penile implant failure rate has been reduced in some series to 8% [27]. *(LEVEL OF EVIDENCE IV)*

2. BOTULINUM-A TOXIN TO REDUCE OUTLET RESISTANCE

Botulinum-A toxin [150 I.U.] injected into the sphincter endoscopically as an alternative to conventional sphincterotomy, has been shown to be effective by some authors [29, 30]. Schurch and co-workers reported that in 21 of 24 patients with detrusor-sphincter dyssynergia, urethral pressures were significantly reduced with a concomitant decrease in postvoid residual volumes in 38% patients. Botulinum-A toxin effects lasted 2 to 3 months making reinjections necessary. They concluded that, although costly, botulinum-A toxin injections, which aim at suppressing detrusor-sphincter dyssynergia but not bladder neck dyssynergia, appear to be a valid alternative for patients who do not desire surgery or who are unable to perform self-catheterisation [30]. *(LEVEL OF EVIDENCE IV)*

3. IMPLANTABLE STENTS AS AN ALTERNATIVE TO SURGICAL SPHINCTEROTOMY

The hope of neurological recovery or improvement is an important psychosocial issue for many SCI patients. They often refuse any procedure, medically indicated or not, if the procedure is destructive and irreversible. The sphincter stent gives the patient a treatment option that is potentially reversible. The UroLume prosthesis is made of a superalloy mesh that expands and shortens, similar to a Chinese finger toy when deployed from the insertion tool. This facilitates the device insertion and removal. The geometry, elastic property, and the radial force of the stent material allow it to maintain its position to continuously prevent obstruction by the external urethral sphincter. The large lumen (42 Fr) created by the prosthesis permits catheterisation and cystoscopy after epithelialization. In 153 patients at 15 centres, sphincter prosthesis placement has documented clinical success with up to two years of follow-up. The simplicity of placement and minimal associated morbidity makes the sphincter prosthesis an attractive modality to treat external sphincter dyssynergia and also in patients with failed previous external sphincterotomy. A prospective randomised study between the UroLume stent versus sphincterotomy at three model SCI centres has just been completed. Patient demographics for sphincterotomy patients (N=26) and UroLume patients (N=31) were statistically similar. Preoperative cystometric capacity, maximal voiding pressure, and residual urine were equivalent between the two groups. The decrease of voiding pressure was significant for both sphincterotomy and stent patients. No significant change in bladder capacity occurred after either sphincterotomy or stent placement. Residual urine decreased in both sphincterotomy and stent patients. The mean length of hospitalisation and operation were significantly shorter for stent patients rather than sphincterotomy [31]. Long-term results confirming the initial results have also been reported [32] *(LEVEL OF EVIDENCE II)*. However there have been several non randomised studies on the use of different stents for the treatment of detrusor sphincter dyssinergia showing disappointing results. The main reported complications are migration of the stent, persisting urinary tract and prostatic infection leading to autonomic dysreflexia, calculus formation, encrustation, tissue growth in addition to pain and irritative symptoms [33 - 36]

B. FAILURE TO STORE

I. SURGERY TO DECREASE DETRUSOR CONTRACTILITY

Patients with neurologic lesions above the sacral micturition centre will frequently exhibit detrusor overactivity [37 - 40]. This phenomenon is responsible for the majority of associated incontinence and may contribute to the development of upper tract deterioration. This latter problem may be exacerbated by the inability to generate a volitional detrusor contraction and the coexistence of detrusor sphincter dyssynergia. Dyssynergia can be predicted if the pontine micturition centre is cut off from bladder innervation [41 - 43]. Poor or absent volitional voiding function will increase residual urine. This will also occur in the presence of detrusor sphincter dyssynergia. More significantly detrusor pressures generated either volitionally or during storage due to the hyperreflexia, may be unphysiologically high, contributing significantly to the development of deleterious upper tract changes. In addition, these changes may be accompanied by the bladder exhibiting low compliance, further contributing to the abnormal bladder pressures generated.

With these pathophysiologic changes in mind, management of detrusor overactivity will be directed at restoring storage function to as close to normal as possible, reducing the associated incontinence and possibility of upper tract changes. This management cannot be carried out in isolation as the patient's ability to empty may be compromised by the lesion itself or the therapy for the detrusor overactivity and must therefore also be considered [44, 45].

Surgery to decrease detrusor overactivity by altering the sacral reflex arc has historically been unsuccessful. Mainly because of this, enterocystoplasty and its alternatives have achieved a 'gold standard' position in the management algorithm of these cases. Continued concern regarding long-term complications of these procedures has prompted several alternatives to enterocystoplasty to be developed. These include gastrocystoplasty, autoaugmentation, ureterocystoplasty and the use of demucosalised bowel segments. This has also prompted a 'resurgence' of methods to peripherally denervate the bladder and the development of techniques to modulate the sacral reflexes. All these techniques will be discussed in the following sections.

1. Enterocystoplasty

It has been accepted practise for many years that patients with intractable neurogenic detrusor overactivity and or low compliance, with associated incontinence and/or upper tract deterioration, can be managed successfully by enterocystoplasty. This assumes that the patient can empty the bladder appropriately, the neurologic disease is not rapidly advancing and that all conservative measures have been exhausted. Despite this, the levels of evidence to support this in the literature are relatively poor. There are multiple series of studies describing retrospective results of this procedure. The results are uniformly good in terms of continence and improvement or stabilization of upper tracts. Many studies also confirm the associated enhancement of urodynamic storage characteristics [10 - 12].

As a general criticism, these papers vary greatly in number of patients studied. They are retrospective in nature and very often refer to a heterogeneous group of patients, not all of whom have a neurological etiology. Techniques, including choice of bowel segment, vary from series to series and many patients require additional surgery (outlet enhancement, reflux prevention, catheterizable stomas etc.) to achieve success. In addition results are not generally evaluated in any standardized fashion, such that there is significant physician bias in the interpretation of results, and attempts to compare series is compromised. Follow up is often too short to be truly meaningful [49 50].

A universal theme found in all, is that complications are common. These include recurrent infection, stones, recurrent incontinence, bowel obstruction, and perforation. More remote complications included malignancy and metabolic abnormalities. The complication rate in some series reached more than 40%. Re-operation rates were similarly high, and intervention was needed both in short and long term follow up (>10 years).

Despite these observations, all authors refer to the overall success of this procedure. However, they do generally qualify this, in their conclusions, by commenting that careful patient selection is required along with life time follow up *(LEVEL OF EVIDENCE IV)*.

2. Alternatives to enterocystoplasty

a) Gastrocystoplasty

Gastrocystoplasty was popularised as a more suitable segment for augmentation in the pediatric neurogenic population. The absence of metabolic acidosis and thinner mucus were some of its advantageous characteristics. There are very few meaningful studies on the use of gastrocystoplasty in the adult neuropath, so discussion of this will be dealt with in the pediatric section.

b) Ureterocystoplasty

Similarly, there are very few papers on the use of this technique in adults.

c) Detrusor myectomy (auto-augmentation)

Detrusor auto-augmentation therapy was introduced in 1989 by two separate research teams, one concentrating on children, and the other on adults. The treatment is intended to allow the bladder to enlarge when the functional capacity is reduced by detrusor overactivity in patients with neurological disease who are refractory to anticholinergic medication, mainly because of adverse effects. Follow-up times of up to ten years have now been published. Pre- and post-operative urodynamic evaluations are available and, because of the neuropathic conditions of these patients, these will be repeated every 1-2 years [52, 53]. A large part of the detrusor muscle is dissected, leaving the mucosa intact and thereby creating an “artificial diverticulum”. This will expand and dissipate the pressure caused by the detrusor contraction and thus allow low-pressure storage. As a result the voiding contraction is reduced as well, and thus patients often need to empty their bladders by intermittent catheterisation after this procedure.

This surgery is generally performed under general anaesthesia. After introduction of a urethral catheter, the bladder is exposed extraperitoneally and filled to anatomical capacity. The peritoneum is dissected from the superior and superior-posterior of the detrusor the urachus, by blunt dissection from the bladder serosa. In trabeculated bladders it may be hard to remove every single muscle fibre, but this will not impair the therapeutic result.

The development of the bladder enlargement is a relatively slow process. It may take about 1-2 years before the final condition of low-pressure storage and eradication of the detrusor overactivity is achieved. During this period medical treatment with anticholinergics (mostly in a much lower dose than before surgery) may be beneficial [54].

In most studies the efficacy of this procedure has been documented by video-urodynamics, pre- and post-operatively. Outcome parameters are: improvement of incontinence, bladder compliance, maximum detrusor pressure during voiding, cystometric capacity, reduced use of anticholinergics, and patient satisfaction [55 - 58].

The maximum detrusor pressures during voiding decrease and the urine residual increases. The cystometric capacity and the bladder compliance both increase. Occasionally, late reduction of capacity, caused by fibrosis, has been reported. In these reports, the surgeons used tissue such as omentum, to cover the serosal side of the mucosa after the detrusor miectomy. However, in the reports from the two groups with the longest experience, this manoeuvre is not supported.

Motivation is extremely important when selecting patients for this procedure. Case reports exist on patients who were changed to intestinal augmentation within 6-12 months of auto-augmentation. Also, patients who will not perform intermittent catheterisation as their mode of voiding are not candidates for this procedure.

A study on 52 adult patients with various neurological (about 75% traumatic spinal cord injury) and a minimum follow-up of 4 years was published recently. The average follow-up was 6.4 years. The only complication noted was per-operative mucosal perforation in one third of the patients. This was easily closed and mostly had no late sequel. The results are encouraging: most patients did not use any anticholinergics, in the others drug use was reduced significantly. The cystometric capacity increased from 132 to 359 ml, bladder compliance from 9 to 25 ml/cm H_2O. The maximum voiding pressure decreased from 95 to 48 cm H_2O, and the residual volume increased from 45 to 163 ml (Figures 8-10). All these changes were statistically significant [58]. Reflux in four out of five patients, was ameliorated, but in one case, de novo reflux was observed. Sixteen failures were reported: nine patients were lost from follow-up and were conservatively counted as failures, four patients were submitted to other procedures, one had a fibrotic bladder, and one required indwelling catheterisation —, and three patients had low capacity after the surgery — one with recurrent infections and the other two had extensive mucosal perforations perioperatively.

In those patients who responded well to auto-augmentation, most were satisfied with their urinary condition, in particular they reported a much better quality of life [58].

In conclusion, detrusor myectomy is a valuable therapy in this difficult patient group, with approximately two thirds of patients responding favourably in the long term. *(LEVEL OF EVIDENCE IV)*. As these patients might otherwise be subjected to intestinal augmentation or sacral neuromodulation therapy, it is worthwhile having this relatively less invasive procedure available. Auto-augmentation does not preclude the use of these other modalities. Although the outcome is generally positive in the long term, a major drawback is the long delay between the procedure and the final result on the lower urinary tract function. This problem may be solved by combining this surgery with botulinum toxin injections into the detrusor. The bladder paralysis caused by botulinum toxin will immediately eliminate the detrusor overactivity and last for about one year.

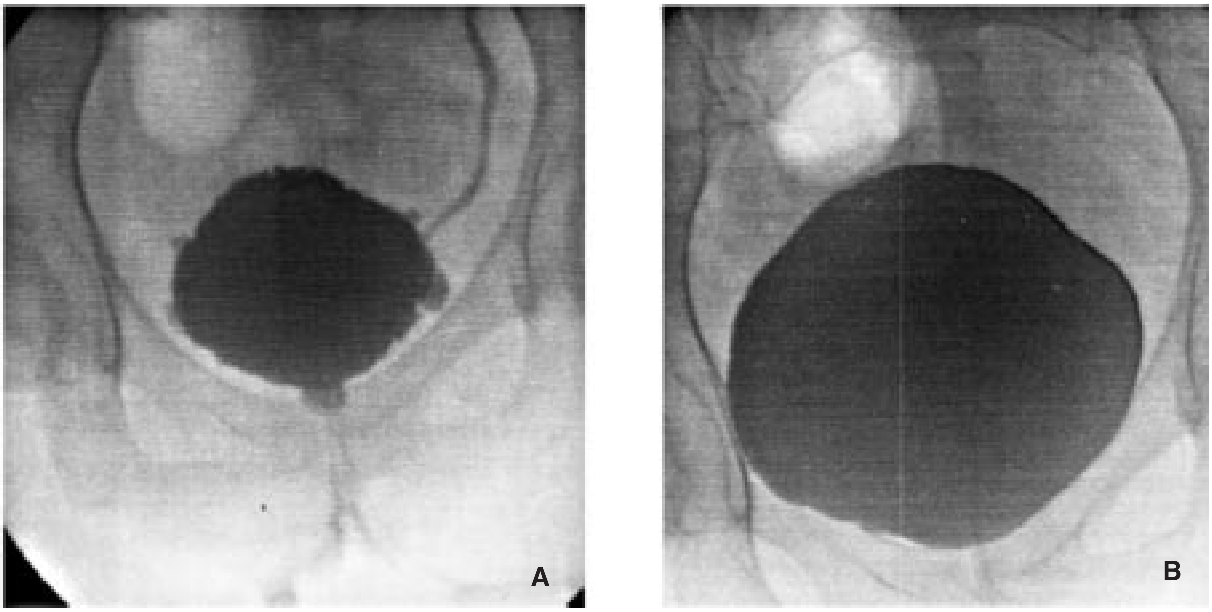
3. Denervation techniques for detrusor overactivity

Historically many techniques have been used and described in the literature to try and convert the overactive neuropathic bladder (upper motor neuron lesion) to an underactive bladder (LMN lesion). These methods will be briefly described. In general they are rarely used now because of poor long-term results, and significant complications.

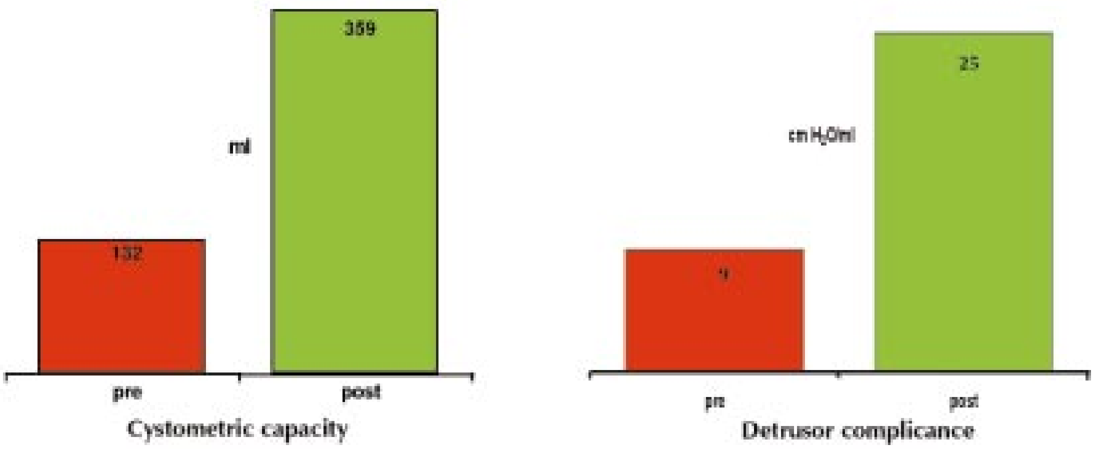
a) Bladder distention (Helmstein's technique): although successful outcome was initially reported, long term results and the occasional reports of bladder rupture have discouraged the establishment of this technique.

b) Cystolysis: mostly used for the treatment of interstitial cystitis and other sensory conditions, with a few series including patients with neurogenic detrusor overactivity. Short-term results reported as good, but no long-term results available. The late complication of bladder contracture in 10% has precluded its further use.

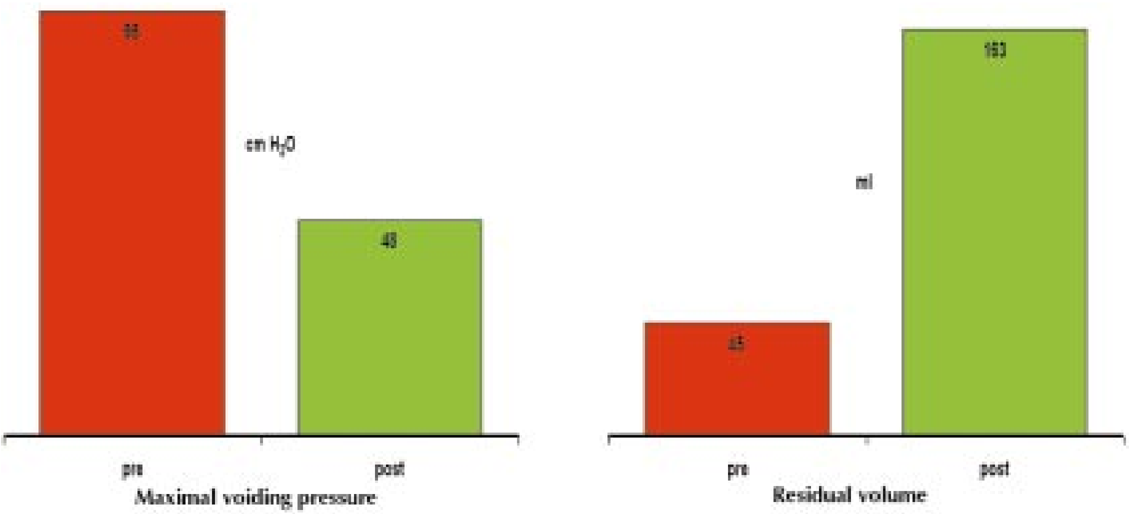
c) Ingelmann Sundberg procedure: transvaginal



Figures 8 a-b : Cystography before and after autoaugmentation (Detrusor Myectomy)



Figures 9 : Bladder capacity and compliance before and after autoaugmentation



Figures 10 : Maximal voiding pressure and residual volume before and after autoaugmentation denervation has been used in patients with detrusor overactivity with some short-term success. Series are all relatively small and there is no experience of this technique in the neurological population.

d) Bladder transection: various techniques have been described ranging from circumferential incision to an endoscopic supratrigonal technique. Patients in these small series were generally suffering from idiopathic detrusor overactivity or had sensory disorders (interstitial cystitis). Studies suffer from short follow up.

e) Subtrigonal injection: the logical extension of the above was the use of phenol or alcohol injected trans-trigonally to effect a denervation of the bladder. Little experience is reported in neurological patients and effects were usually short lived. The occasional complication of fistula formation has further doomed these procedures to the 'history' books.

f) Sacral rhizotomy: Of all the techniques used to denervate the overactive detrusor, sacral rhizotomy has achieved the best success. In most series, presently, it is combined with implantation of sacral anterior root stimulator. In this way the overactivity is significantly reduced and functional bladder capacity is increased [4] [5], [7] [8]. The stimulator allows the patient to empty the bladder without resorting to catheterisation. The rhizotomy also reduces the development of sphincter dysynergia during anterior root stimulation.

Rhizotomy is conventionally performed via a limited sacral laminectomy to expose S2-S4 nerve roots bilaterally. Visual magnification and continuous cystometry aid identification of the appropriate nerve roots. The nerves that evoke an adequate detrusor contraction when stimulated, are selected and severed.

Reported complications include fecal incontinence and erectile dysfunction. The later may be overcome by using the anterior root stimulator for this purpose. Fecal incontinence is rarely reported in published series [5] [6] [8]. *(LEVEL OF EVIDENCE IV)*

Recent developments focus on techniques to reversibly block the posterior roots during stimulation so that formal rhizotomy could be avoided. A technique using cryotherapy to produce a reversible nerve block has recently been described [10].

4. Sacral nerve stimulation / neuromodulation

Suppressing detrusor overactivity using a neuromodulation approach has been in the development stage for many years. Presently several clinical studies are available to demonstrates the efficacy of this technology. Unfortunately there are no good studies on its use in the neurogenic bladder patient. The exact mechanism, by which sacral nerve stimulation inhibits detrusor contraction, is not fully understood. However it is thought that sacral nerve stimulation induces reflex mediated inhibitory effects on the detrusor through afferent and or efferent stimulation of the sacral nerves. In addition activation of the pelvic floor muscles may occur via stimulation of the somatic fibers of the nerves, causing further detrusor inhibition [59].

The technique of initial percutaneous nerve stimulation to assess efficacy, followed by surgical implantation of the sacral nerve stimulator is well known.

Several reasonable clinical studies are available showing significant reduction in incontinence episodes etc. Unfortunately, as stated, the majority of patients in these studies, suffered from refractory urge incontinence and those with neurological conditions were specifically excluded. Complications of the technique included pain at implant site, infection, change in bowel habit and technical problems including lead migration [59].

This technique is certainly a promising development in a difficult group of patients. Technical details still need to be improved and although initial reports are encouraging [60], [61] it remains to be seen if this will be appropriate for neuropathic patients.

In general, surgical intervention to decrease detrusor contractility should still only be used when all conservative measures have failed. Choice of intervention at present will depend on many factors including the underlying pathogenesis of the condition, its natural history, the patients mobility, motivation, age and home support, to name the most significant. Although augmentation cystoplasty gives the most reproducible results its complication rate is still relatively high. Of the alternatives to cystoplasty, only autoaugmentation has some merit but will have to be carefully evaluated in the long term. Neuromodulation and denervation techniques such as rhizotomy have less morbidity than cystoplasty and their role will continue to evolve. The most pressing need in this field is to develop standardised methods of evaluating results. It is too much to ask for controlled trials for these surgical techniques, but a uniform method of assessing results would be extremely helpful.

5. Botulinum A toxin injections in the detrusor

This new therapy was used for the first time in 1998 and published in 1999. Subsequently, several clinical studies have been published including pre- and post-operative urodynamic evaluation and a follow-up time of up to three years. Patients with detrusor overactivity, refractory to anticholinergic medication, are suitable for this therapy [62 - 66].

The botulinum toxin blocks the local intramuscular nerve endings. This causes a flaccid paralysis of the detrusor that persists for several months. All patients must be established on intermittent catheterisation before embarking on this therapy. The combination of both these modalities leads to low pressure storage without upper tract damage and continence 62 - 66.

Botox® 300 IE or Dysport® 900 IE are approximately equivalent doses of botulinum A toxin. The agent is dissolved in 15 ml saline and injected in 0.5 ml aliquots over the whole of the detrusor using a standard endoscopic injection needle. The injections are performed preferably in visible muscular structures. The trigone and the ureteric orifices are spared, as is the bladder neck, in theory, preventing the development of post-injection stress incontinence.

The effects of Botox can be demonstrated within 7-14 days after the application. Over 100 patients have been treated in two centres (Murnau and Zurich). The majority of these patients had traumatic spinal cord lesions, but smaller groups with multiple sclerosis and myelomeningocele have also been treated. Patients with low bladder compliance secondary to neurological disease, caused by changes in the detrusor wall are excluded from this treatment. Patients at risk from autonomic dysreflexia are treated under local or general anesthesia.

In the published studies efficacy was documented by video-urodynamics, pre-operatively and at 6, 16, and 36 weeks after treatment. The outcome parameters were continence, functional reflex volume, bladder compliance, maximum detrusor pressure during voiding, cystometric capacity, reduced use of anticholinergics, and patient satisfaction 62 - 66.

In the vast majority of cases it was found that the detrusor overactivity was reduced, the functional reflex volume and cystometric capacity had increased, and the patients were continent.

The maximum detrusor pressures during voiding had decreased. The urine residual was almost always equal to the cystometric capacity. An improvement in autonomic dysreflexia was noted. About 5% of the patients did not respond to this therapy for unknown reasons. The authors suggest that these patients might have been in contact with the toxin earlier in their lives, and had developed antibodies. A single injection session offers therapeutic benefit for up to14 months, with most patients averaging between 10 and 12 months. Presently, 15 patients with a minimum follow-up of three years have received three injections, apparently without loss of efficacy 65, 66.

This therapy is very well tolerated by patients, two thirds of them are completely continent, with some individuals reporting consistent bladder capacities of up to 800 ml.

In October 2000 an interim analysis was carried out on 43 patients. Forty patients had six weeks follow-up, and 24 had 16 weeks follow-up. The number of patients with 36 weeks follow-up was too small for evaluation. In this analysis, continence had improved and the detrusor overactivity had ameliorated significantly (Figure 11). The functional reflex volume increased from 178 to 412 and to 366 ml, the cystometric capacity from 284 to 487 and to 478 ml, the maximum voiding pressure decreased from 74 to 33 and to 24 cm H_2O, and the residual volume increased from 237 to 501 and to 508 ml. All these changes were statistically significant. The compliance increased non-significantly, probably because abnormally low compliance was excluded. It was noted that existing autonomic dysreflexia was also ameliorated.

Responders to this therapy (about 90%) will be completely continent and are able to stop or reduce the use of using anticholinergics. Both products seem to be equally effective. The detrusor paralysis lasts at least 10 months. This treatment is a safe and an impressive alternative when other methods for reducind detrusor overactivity have failed. This method is suitable for patients with neurogenic lower urinary tract dysfunction and detrusor overactivity, who can perform intermittent catheterisation. No adverse events have been reported up till now. This therapy may be combined with auto-augmentation, improving the development of low-pressure storage. 64 - 66 *(LEVEL OF EVIDENCE IV).*

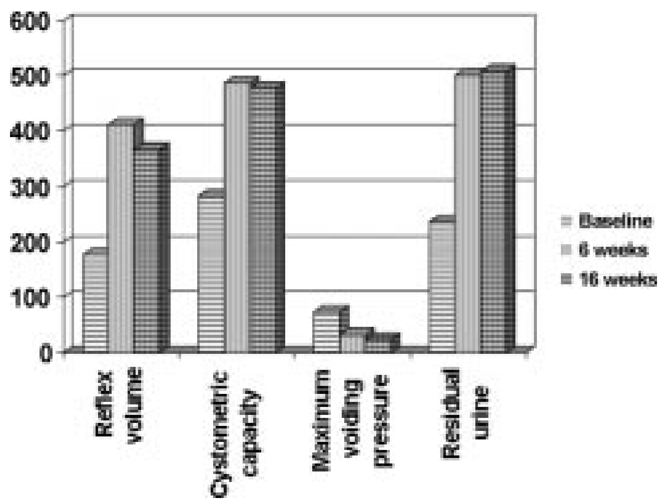


Figure 11 : Reflex volume, bladder capacity, maximum voiding pressure and residual urine at the baseline, 6 and 12 weeks after the inyection of Botulinum-A toxin at the detrusor.

II. SURGERY TO INCREASE SPHINCTERIC RESISTANCE

Patients with sphincteric incontinence due to neurologic disease or injury are candidates for surgical procedures to increase urethral resistance, assuming that associated bladder compliance and detrusor overactivity abnormalities can be satisfactorily managed. As all procedures to increase urethral resistance in neuropathic patients produce compression, urinary retention is not uncommon after the surgery.

Patient selection and preoperative evaluation play a critical role in the process of increasing urethral resistance. The work-up should include history and physical examination, urine culture, cystourethroscopy, upper urinary tract imaging and urodynamics.

The minimal conditions that a neurological patient should meet in order to be considered as a candidate for any of these procedures are:

- incontinence primarily due to intrinsic sphincter deficiency
- an acontractile detrusor or controllable detrusor overactivity
- a healthy, well-vascularized bulbar urethra or bladder neck
- absence of significant vesicoureteric reflux.

In addition the patient should have sufficient intelligence, motivation, compliance and manual dexterity and must be established on intermittent catheterisation. The neurological disease should be stable. Thus patients who have a progressive disease such as multiple sclerosis, are generally poor candidates.

There are several surgical options to increase urethral resistance in neuropathic patients. These include artificial urinary sphincter, sphincteric muscle augmentation, implantable valves and bulking agents. The rational for procedure selection depends on a number of patient's factors and the surgeon's preference and experience.

1. Artificial urinary sphincter

Although the artificial urinary sphincter (AUS) has been recommended for the treatment of sphincteric incontinence, and it is commonly used in patients with congenital neurological disease, there has not been a significant degree of popularity or success in the adult neurogenic population. In most of the reported series, the difference between the number of patients initially implanted and the number of patients using the device at the end of follow-up is unclear. Success rates reported range from 70% to 95% with a revision rate varying between 16% and 180% [67 - 77]. In a recent review on long-term outcome (more than 10 years) of 100 patients treated with the artificial urinary sphincter it has been shown that, in spite of the high revision rate, the artificial urinary sphincter is an effective long-term treatment for incontinence in male patients. In female patients the risk of erosion is high, although overall long-term continence is satisfactory [78] *(LEVEL OF EVIDENCE IV)*.

Changes in bladder compliance leading to upper urinary tract deterioration may occur with any procedure to increase outlet resistance without bladder augmentation. This problem has been most frequently associated with the artificial urinary sphincter. The mechanism of these changes in bladder function is not fully understood but clearly the myelodysplasic population is most at risk [79]. Changes in compliance after artificial sphincter implantation are not documented in the adult incontinent population without myelodisplasia. It has been suggested that these changes might be associated with an increase of the alpha-adrenergic innervation [80], but could also be related to detrusor behaviour, not identified preoperatively. When post-treatment urodynamics reveals detrusor overactivity not demonstrated preoperatively, anticholinergic therapy is needed. If maximal doses of anticholinergic drugs do not control the detrusor overactivity, bladder augmentation may be necessary. Timing of the augmentation procedure in these patients, simultaneously or subsequently, is controversial alternatively. This procedure may be carried out as a first stage, prior to the sphincter implantation. It may be performed simultaneously, or as a secondary procedure if abnormal bladder behaviour is unmasked. Some authors advocate a staged approach, fearing sphincter infection if implanted at the same time as the cystoplasty [79]. Conversely other authors have not found a higher complication rate using the synchronous technique (Figure 12) [69 74]

2. Sphincteric muscle augmentation

a) Dynamic myoplasty

Attempts have been made to correct intrinsic sphincter deficiency using a stimulated Gracilis muscle flap (dynamic myoplasty). First reported by Janknegt et al [81], initial experience has been gained in men and women with neurologically impaired sphincter function. Its use is based on the transposition of this muscle to the bladder neck [82] or to the urethral area [83]. The skeletal muscle is then converted into a functional sphincter by electrical stimulation. During an increasing stimulation protocol the fatigable type 2 fibres, the main fibres in skeletal muscle, are replaced by type 1 fibres, which can sustain long lasting contractions. A

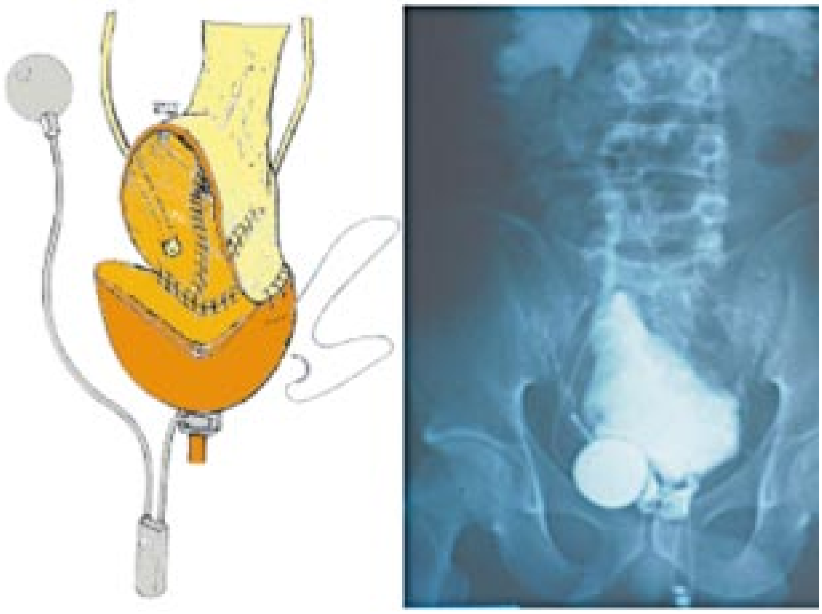


Figure 12 : Simultaneous bladder augmentation and artificial urinary sphincter implantation

subcutaneously placed pulse generator provides continuous low current electrical stimulation via electrodes, enabling the maintenance of constant sphincter tone. Urination is achieved by temporary termination of the neuromuscular stimulation. There have been very few reports on the dynamic graciloplasty for the treatment of urinary incontinence although results are encouraging with few complications. Presently, this technique could be applicable in incontinent patients with severe sphincteric intrinsic deficiency who are not candidates for conventional treatment, including the artificial urinary sphincter, or in whom such treatment has failed [84].

b) Slings

There have been many reports on the success of pubovaginal slings (PVS) for the treatment of intrinsic sphincteric deficiency in the neurogenic population in both children and adults. The procedure is established in the neurological female patient as an alternative to the artificial urinary sphincter. It should be assumed that following PVS, patients will have to empty their bladders by intermittent catheterisation [85]. The reported continence rate is generally high [86 - 88], with few complications, including difficulty with catheterisation, ventral hernia at the graft harvest site, bladder calculus and detrusor overactivity [89]. There have been a few reports using slings to correct male neurogenic urinary incontinence. Although some authors recommend its use in these patients, it is a procedure that has not gained widespread acceptance. The number of male patients in each series is small and there is a lack of long-term outcome [88 90 91 92]. Walker et al have reported their results in a series of 15 patients with a 3-year followed-up who underwent a rectus fascial wrap. They found continence rates comparable to that of other bladder neck sling procedures in patients with spina bifida [93].

Recent reports suggest that the bulbourethral sling procedure for male incontinence, achieves continence by increasing urethral resistance in a dynamic fashion when intra-abdominal pressure increases, similarly to the pubovaginal sling used to treat female stress urinary incontinence [94] *(LEVEL OF EVIDENCE IV).*

c) Bulking agents

Periurethral injection of materials to provide bulk for urethral closure and continence has applicability for patients with neurogenic vesico-urethral dysfunction, although this has not gained much popularity. The reported continence rates achieved with the use of bulking agents in children ranges from 30% to 80% in the short term and 30% to 40% in the long-term [95-100]; At present there are no studies reporting the use of bulking agents in the adult neurogenic population.

3. IMPLANTABLE VALVE/CATH

During the last few years several intraurethral implantable devices for the treatment of intrinsic sphincteric incontinence in women have been introduced. The reported success varies in between 72 % and 94% [104,105]. High withdrawal rates have been observed in most studies as well as a significant number of complications. These include device migration, leakage around the catheter or through its lumen, blockage of the valve by sediment or stone formation, urinary tract infection, urethral/meatal bladder irritation, device malfunction and hematuria [106 107].

A remote controlled intraurethral insert has been used for artificial voiding. In 49% of the patients the device had to be removed due to local discomfort or urinary leakage around the insert, rendering the results unsatisfactory [106], [107].

In summary, there are several alternatives to surgically manage urinary incontinence due to neurogenic sphincteric incompetence. Increasing urethral resistance is possible only in those patients who have a good bladder capacity and accommodation or pharmacologically controlled detrusor overactivity. Otherwise when planning to increase the urethral resistance in these patients, bladder augmentation procedure should be considered. The implantation of an artificial urinary sphincter is the technique which has gained most popularity and which has passed the test of the time. As an alternative to the artificial sphincter a sling procedure might be use, assuming that the patient can perform intermittent catheterisation. Dynamic myoplasty appears promising although a cost-efficacy analysis needs to be done. Intraurethral valves need to be evaluated with longer follow up before they can be accepted. Bulking substances may play a limited role in the treatment of neurogenic sphincter deficiency.

III. BLADDER REPLACEMENT SURGERY

1. Orthotopic bladder

This technique aims to create a low-pressure reservoir in patients with severely damaged bladder wall by a partial cystectomy replaced by a substitution cystoplasty [108 - 110] A severely thick and fibrotic bladder wall can result from supra sacral neurogenic bladder often complicated with recurrent infection or stones. Urodynamics usually shows detrusor overactivity associated with high intravesical pressure, severe low compliance and reduced bladder capacity. Failure of conservative treatment is an indication for bladder surgery. In these cases, conventional augmentation cystoplasty cannot be used and the majority of the diseased bladder wall needs to be excised. The cystectomy in these cases is supratrigonal, leaving the bladder neck and the trigone intact. The ureters are left in place or reimplanted in the intestinal segment if high-grade reflux or an abnormal urethrovesical orifice is identified.

Numerous factors must be taken into consideration. Urethral stricture or other outlet abnormality must be excluded. The patient must be able to carry out intermittent catheterisation (often this non-contractile reservoir and persistent dysynergia require catheterisation to empty); the patient's must be taught to perform catheterisation before surgery. Urethral sphincter deficiency can be treated by a sling [111] or implantation of an artificial sphincter [112]. These may be performed simultaneously or be held in reserve if it is anticipated that the reduction in bladder pressure by the orthotopic bladder reconstruction alone will be sufficient for continence.

The choice of bowel segment and configuration of that segment may differ but most authors agree that the segment should be detubularized in order to achieve a large capacity and a low-pressure reservoir according to Laplace's law. The segment of bowel used is often a 40 cm length of terminal ileum reconfigured in an S or W shape. Resection of a longer segment of ileum may be associated with diarrhea; due to the increased amount of bile acids reaching the colon [113] This risk is increased in myelomeningocele patients and in those with short or diseased intestine. The diarrhea often resolves with diet and medication. The use of the caecum with the adjacent terminal ileal has been advocated, but ileocecal valve resection aggravates the risk of digestive disturbance due to reduction in transit time compared to ileum alone. The true incidence of diarrhea after the resection of ileum, ileocecal valve or colon is not known [113]. Absorption of urinary components, particularly chlorides can lead to metabolic acidosis when large resection or proximal ileum resection is associated with renal insufficiency, but in limited ileal resection and normal renal function patients do not develop acidosis [114]. In time, villous atrophy reduces the bowels absorptive properties as well as mucus secretion [115]. Incomplete emptying and mucus stagnation can lead to bladder calculi. Although bladder stones can develop in all types of neuropathic bladder, the main risk is intermittent catheterisation. However, the incidence of stones does not seem to be influenced by enterocystoplasty [116]. In a few cases, spontaneous overdistension leading to perforation has been reported [110] The precise risk of malignancy in intestinal segments used for urinary reconstruction [117] is unknown. The incidence of adenocarcinoma of the ileum is far less than that of the colon. There is no consensus on cancer surveillance in these patients, but abnormal symptoms and hematuria should be investigated.

Ureteral reflux on pre-operative cystography is corrected by an antireflux procedure, as part of the reconstructive surgery. Severely dilated ureters can be reimplanted into the pouch using either an extramural tunnel, or a mucosal sulcus (Le Duc/Camay) or long afferent loop of bowel (Studer). Severe impairment of renal function is a contraindication, but this surgery can be considered if renal transplantation is planned. Low urine output after reconstruction, will require bladder irrigations in order to prevent mucus retention and pyocystitis. *(LEVEL OF EVIDENCE IV)*.

2. CONTINENT DIVERSION

Continent cutaneous urinary diversion provides an alternative bladder outlet associated with a valve for urinary continence, which is catheterised to empty. The urinary reservoir must have low pressure and good capacity. The continent catheterisable stoma can either be implanted into the native bladder or into an intestinal neo-reservoir. In most cases of supra sacral neurogenic lesions and myelomeningocele, a bladder augmentation is carried out at the same procedure. In some cases the native bladder outlet needs to be closed to achieve continence. This is a difficult procedure, with recanalization observed in up to 25% [118]. In men a secondary closure may be particularly difficult but in women a secondary closure can be carried out transvaginally. If the bladder outlet is suitable, it may be preserved, maintaining continence with either a sling or endoscopic transurethral injections [119], or just left as access to the bladder and as a pop-off mechanism [120].

Indications for a continent catheterisable stoma are: inability to perform self-catheterisation through the normal urethral route. This may be due to severe urethral stricture, severe outlet lesions i.e. erosions related to permanent indwelling catheter, urethral pain, non accessible meatus (obesity or upper limb neurogenic partial deficit or spinal abnormalities, transfer difficulties or psychological factors). An additional factor is intractable incontinence particularly in women and in men with condom problems.

If patients are to be managed safely with long term indwelling catheters, they must adhere to a strict care guidelines to avoid complications. Thus altering management to a continent stoma, may be a better prospect. In addition, in some tetraplegic patients, a continent abdominal stoma is much more accessible and requires less dexterity than catheterising the native urethra [121].

In some patients a continent reconstruction may be performed in conjunction with orthopedic procedures. In other patients, the continent stoma provides easier bladder access for the patient's attendants. Finally, a continent stoma provides better self-image than an external appliance, thus further improving quality of life.

The continent conduit is constructed using the appendix or a segment of ileum, although the ureter or fallopian tube has been used occasionally [122]. If the conduit is as narrow as to admit a 14 Ch catheter, it can be implanted in a submucosal tunnel in the bladder or neo-reservoir. The Mitrofanoff procedure uses the appendix [123 - 125] and the Montie procedure [126 - 127] uses a short ileal or colonic segment sutured transversally. A narrow continent conduit can also be constructed by tapering the terminal ileum segment if it is combined with a right colon pouch (Indiana etc.). The continence mechanism in this case is the ileocecal reinforced by ileocecal plication [128 - 130]. Other techniques that have been used in conjunction with ileal reservoirs are the intussuscepted ileal nipple (Kock) [131], or the Benchekroun hydraulic valve [132]. Whichever mechanism is used, continence rates of more than 80% in short term has been reported. Unfortunately complications are relatively frequent, especially with longer tubes and with intussuscepted valves (dessusception, parastomal hernia, fistulae) [133] compared to narrow tube techniques [134]. These small bore-outlets (Mitrofanoff, Yang-Montie) are currently the commonest techniques used. They are however not without their own problems, with stoma stenosis being reported in 12 to 30% of cases. Liard [135] reported on 23 Mitrofanoffs continent with a minimum of 15 years follow-up. Complications that require surgical revision were: stomal stenosis or persistent leakage in 11 cases. Stenosis, particularly at skin level can be simply dilated or a V flap advancement used if necessary. The umbilical site for the stoma is popular and has cosmetic advantages, but may have a higher risk of stenosis [136]. Bladder stones can be treated endoscopically through the conduit or through a percutaneous route [137]. If the urethra is closed, patients should be advised to perform frequent and regular catheterisations and also to perform bladder irrigation through a catheter of minimum size, in order to evacuate the mucus. Metabolic disorders can occur in association with these reservoirs. A 20% rate of hyperchloremia has been reported without significant acidosis (Lockhart 128). Vitamin B12 deficiency and cholelithiasis have been reported but occur very rarely [113] *(LEVEL OF EVIDENCE IV)*.

3. CONDUIT DIVERSION

The indications for conduit (non-continent) supravesical diversion have been reduced significantly since the introduction of appropriate management, such as intermittent catheterisation, in these patients however this procedure may be considered in the case of intractable incontinence in bed bound patients, the devasted lower urinary tract following multiple failed surgery or where the use of long bowel segments for reconstruction is contraindicated (short bowel syndrome), It may also be considered in patients who do not accept the potential complications of a continent diversion, who are not able to perform catheterisation, or where the upper urinary tract is severely compromised. Proper location of the stoma must be determined before surgery by stomatherapist and urologist. This location is especially important in patients who are chair bound or who have specific deformities, such as patients with severe kyphoscoliosis or a small abdomen. The most common technique is to use a short ileal segment with the ureters anastomosed directly end to side. There is no evidence that an antireflux procedure is required and this may in fact increase the risk of implantation stenosis. Patients should be followed up indefinitely as stomal stenosis and or ureteric anastomotic stricture can occur years after surgery. Large bowel segments can be used when patients have a severe renal insufficiency in order to prevent metabolic disorders [138]. In the long term, complications will occur, namely pyelonephritis and calculi. Renal impairment has been estimated to occur in 16.5% to 50% of patients with 10 years or more follow-up [138 - 140] *(LEVEL OF EVIDENCE IV)*

4. Undiversion

Conversion from a conduit to a continent diversion or to the reconstructed bladder, may be indicated in few cases. Such patients will usually have been diverted many years ago when the newer technologies described above were not generally available. This will usually be considered in younger patients who have a strong desire to improve their body image by avoiding the use of an external appliance [110, 141, 142]. These young adults must be carefully counselled and must be compliant in following the medical instructions. The conduit can be anastomosed to the reconstructed bladder or to a continent self-cauterised pouch [128]. In some cases it can be anastomosed to the rectum [141-143] The latter is an internal diversion that requires normal faecal continence and an efficient ureteral antireflux mechanism. It must be remembered that it does expose the patient to a greater risk of renal deterioration than external diversion *(LEVEL OF EVIDENCE IV)*.

C. THE FUTURE BLADDER

1. Essential design characteristics

The need for bladder replacement because of malignancy or voiding dysfunction is a significant clinical problem. Numerous cystectomies and/or diversions are performed worldwide annually as a method of treating these maladies.

If an effective prosthetic bladder were available, it could be used in all of the above patients. It could also be used in a large proportion of the unquantified number of patients who are considered unsuitable for cystectomy and diversion because of unsuitable bowel or infirmity. Many patients who are being treated primarily with radiotherapy for bladder carcinoma might also receive primary surgery if prosthesis were available [144, 145]. The proposed advantages of an alloplastic bladder, over methods of bladder substitution, are listed in Table 1. The characteristics required of the ideal prosthetic bladder are outlined in Table 2.

Table 1 : Advantages of prosthetic bladder

* Decreased peri-operative morbidity and mortality due to reduced operating time
* Availability of a device for all patients
* Postoperative complications related to the use of intestine, such as metabolic acidosis, anastomotic leaks, stoma problems, bowel obstruction, polyuria and cancer risk, would be avoided
* Complications related to inherent deficiencies of homologous tissue such as infection, mucous production and effects of prior irradiation would be avoided
* The ability to irradiate the pelvis without risk to the urinary reservoir.

Table 2 : Characteristics of an ideal prosthetic bladder

* Preservation of renal function
* Continent collection and adequate storage of urine
* Voluntary voiding without residual
* Easy to construct, insert and repair
* Biocompatible and does not degrade or shrink with time
* Does not interfere with the function or other organs.

2. Developing a prosthetic bladder

The bladder has a number of complex features which are different to recreate, so much research is needed to develop a prosthetic bladder which can effectively substitute for these functions. The rate of progress in developing such a prosthesis will depend on

the interest of urological surgeons in the subject and on the amount of energy and enthusiasm with which the idea is promoted to the biomedical industry and healthcare providers. The degree of interest shown by the biomedical industry will also depend on the future need for a prosthesis, which is directly related to the potential bladder augmentation and cystectomy rates. In the recent past, there have not been any dramatic changes in the indications for these procedures. There has been some movement away from radiotherapy as first-line curative treatment in those countries where it is used, so a rise in cystectomy rates may well follow this trend particularly for patients with localized tumours. If effective chemotherapy is found for the treatment of transitional cell carcinoma, the number of patients who require cystectomy may well be reduced. On the other hand, chemotherapy could also make some patients, who are now thought to be inoperable because of locally extensive cancers, suitable for cystectomy by reducing the tumour mass to a resectable size. Patients with impaired renal function, who are not suitable for ileal conduits or bladder substitution with bowel and may be denied a cystectomy, would benefit from the availability of a prosthesis. Increasing numbers of patients are having intestinal augmentation or substitution of the bladder for functional disorders of the bladder. These patients would also benefit from an effective prosthesis. The numbers requiring such treatment for functional disorders will probably decrease again in the future as advances are made in electrostimulation of the pelvic nerves [146], [147]

3. Protection of renal function

One of the primary objectives of a prosthetic bladder is to preserve renal function. In future work, this function will have to be studied more carefully than it has been in the past. Development of hydronephrosis on an intravenous urogram is not a sensitive enough method of following changes in renal function [148 - 156]. Monitoring changes in serum creatinine is also too vague to be of value in assessment of changes in the function of a prosthesis as it is delayed reaction and does not clearly identify what deficiencies in a design model are interfering with renal function. Direct measurement of renal function is required. Similarly, awaiting the development of complete obstruction or the results of postmortem examination of the specimens are not acceptable modes of determining how well a prosthesis is functioning [148 - 156]. Future models will have to incorporate in their structure, methods for recurrent, or preferably continuous, monitoring of pressure [157],[158] urine flow rates and even urine constituents. Ideally, these should take the form of telemetric monitoring to avoid any external leads or connectors. These features will be essential, in future prototype bladders, so that definitive data can be collected on the effects of alterations in flow rates and pressures on renal function rather than depending on the intuitive approach used to date. In reality, most of the pressure and flow work can be done by bench studies in the laboratory.

The main cause of renal failure in most prosthetic bladder studies, when luminal occlusion and leakage are excluded, has been adynamic obstruction due to the large mass of fluid sitting in a passive prosthesis against which the kidney and native ureter have been expected to excrete more urine. If renal function is to be protected, some method of ensuring that urine drains into the bladder without either occlusive or non-occlusive resistance will have to be included in future prosthetic designs. This can be ensured by having a negative pressure draw the urine down, as in the Mayo [151], [158], [159] and Aachen [148] models, or a positive-pressure mechanism which pumps urine down the ureter into the bladder. The latter would probably be more difficult to achieve as it would require continuous movement in the pumping mechanism and thus be more prone to mechanical failure. It would also require a continuous source of energy while the negative-pressure principle only requires a pumping action during bladder emptying and then the energy is stored, e.g. in a compressed spring, for use during the filling phase. A spring mechanism could conceivably be used to provide continuous energy, as used in clockwork mechanisms. Transcutaneous magnetic energy coupling is a mechanism which enables electrical power to be induced intracorporeally, with the use of magnets, without the need for internal batteries or percutaneous wires. It could be used to provide energy to create continuous positive or negative pressures but this would mean that the patient would have to wear a sizable battery pack continuously. Transcorporeal energy coupling would be very useful when an intermittent energy source is needed, such as during bladder emptying.

4. Filling, voiding and continence with the prosthetic bladder

From the research that has been done to date, there appears to be two directions for creating the actual structure of the artificial bladder. The first is to have a rigid outer shell which protects the bladder from any external compressive forces. A mechanism which allows outflow of urine during emptying is also necessary. In the Mayo bladder, this takes the form of a 300 ml reservoir but with modifications to the model this could be reduced to 20 ml. These rigid bladders will be placed in an extraperitoneal position, either subcutaneously or subfascially, to avoid the problem of fibrous capsule formation, bowel adhesion and ascites. A pump mechanism will be necessary to evacuate urine. This pump could be manually operated or be driven by a transcutaneous magnetic coupling device. The second approach, to the replacement of the storage and evacuation functions of the bladder, is to design a prosthesis with a semi-rigid shell. It would have to be stiff enough to resist the compressive forces of body tissues, and would have to be placed subcutaneously so that it could be emptied by manual compression. This is a simpler design concept but it would require a significant design effort to find an effective model which would be cosmetically acceptable and would have the capacity to manage urine production rates in the human. The surface of either design should be roughened to reduce the degree of tissue reaction. It would even be better to cover the shell with a bonded ingrowth material such as Dacron or Proplast to reduce movement and tissue reaction [148],[149], [155] Advances in material research may allow a swing back from the rigid bladders to the collapsible bag idea. This system could possibly work if formation of a fibrous capsule around the bladder, which prevents its expansion, could be avoided. To do this, the surface which would be in contact with the intra-abdominal contents would have to be made from , or coated in, a material which would not induce an inflammatory reaction in the surrounding tissues. Hydrogels go some of the way to fulfilling this function, as they provide a moist lubricated surface, but further advances are still necessary. Ideally, this material should also allow gradual ingrowth of peritoneum without fibrosis enabling the prosthesis to be isolated from future intra-abdominal problems. The surface of the collapsible bladder, in contact with the back of the abdominal wall and the raw area are left after cystectomy, would be covered with an ingrowth material. It would be essential that adhesions could not form between this coating and bowel. Dense fixation of the bladder would reduce mobility and lessen tissue irritation. It if could be made to work effectively, the collapsible bladder would be the simplest, and thus most reliable, prosthesis available.

Mechanical reliability is an essential requirement for many prosthesis. This has been a problem with all bladder prostheses particularly the more complex designs [149, 157, 158]. This has nearly always been due to failure of the parts of the prosthesis and not to the implantation itself. Any future designs should be extensively bench tested before any in vivo studies are performed. Reliability of the parts and completed models should be ensured, before considering implantation, by extensive repeated testing on the bench under much wider ranges of pressures, fluid flow, moisture and temperature than could ever be experienced within the body. Short-term in vivo studies, of a few weeks, provide little added information over bench work because any functioning, non-infected prosthesis will have minimal negative effects on the laboratory animal and, conversely, the laboratory animal's system will not develop the reactions which can damage or interfere with the functioning of the prosthesis. The methods of preventing early failure of a prosthesis because of leakage or obstruction have been identified and do not need to be rediscovered. Thus, only long term in vivo studies should be required from now on.

Future models will have to provide excellent continence. This could be done by providing some feedback so that the patient can tell when the bladder is near to capacity rather than having to wait for the first few drops of overflow before he/she knows that the bladder is full. Sensors could monitor the volume or the pressure in the bladder. The patient could be alerted by an auditory signal, or by a mild subcutaneous electrical current. If, in future models, a satisfactory anastomosis can be made directly to the urethral sphincter, then the patient could be warned by a signal directed to the sphincter area giving the patient a natural feeling of having to pass urine. The external sphincter would then be relaxed voluntarily. If the neural control of the sphincter were damaged then the electrical signal could be used to actively control the sphincter.

While intraluminal access, through a stoma or subcutaneous injection port, would have the benefits of being able to monitor pressures directly, to perform contrast studies, and allow cleaning of the prosthesis, the risks of infection are too great to allow this feature to be included in future bladders. Further advances are needed in material research to find a substance which has the ability to prevent infection on a long-term basis.

The urethra will, however, always be the weak point of any alloplastic bladder because it is a connection to the outside world which provides a point of entry for infection. The urethra, although only a small part, is probably the area on which most future research and development will have to be performed if a viable prosthesis is to become a reality.

If development of an effective prosthesis is to advance the desire for short-term gain, an early publication of results must be resisted and long-term research and investment must be instituted.

RECOMMENDATIONS OF THE COMMITTEE

As with all surgery on the urinary tract, certain principals must be adhered to in establishing the appropriateness of any procedure. These are: 1) preservation of renal function and 2) control of incontinence. In addition, for patients with neuropathic bladder, other issues need to be considered, namely:1) social circumstances, 2) degree of disability, 3) cost effectiveness, 4) technical difficulty and 5) complications.

Surgical treatment for the neuropathic patient is actually focused to enhance detrusor contractility, to decrease outlet resistance, to decrease detrusor contractility, to increase sphincteric resistance or to circumvent the bladder.

A. SURGERY TO ENHANCE DETRUSOR CONTRACTILITY

Sacral anterior root stimulation combined with sacral posterior rhizotomy is a valuable method to restore bladder function in selected spinal cord injury patients suffering from hyperreflexia refractory to medical therapy *(LEVEL OF EVIDENCE IV)*.

B. Surgery to decrease outlet resistance

Transurethral incision of the external sphincter is a reasonable option to adequately drain the bladder and prevent urologic complications in the spinal cord injury male patients *(LEVEL OF EVIDENCE IV)*. Intraurethral stents are showing promise as shown in prospective randomised clinical trials *(LEVEL OF EVIDENCE II)*.

C. Surgery to decrease detrusor contractility

Although there is a lack on prospective randomised studies, enterocystoplasty has passed the test of time in order to achieve a low pressure reservoir *(LEVEL OF EVIDENCE IV)*. As alternatives to this procedure it has been proposed the autoaugmentation and the injection of Botulinum-A toxin at the detrusor level *(LEVEL OF EVIDENCE IV)*.

D. Surgery to increase sphincteric resistance

Although there is a high revision rate Artificial urinary sphincter implantation remains a good option for the treatment of sphincteric incompetence in selected cases *(LEVEL OF EVIDENCE IV)*. In spite of a lack of long-term follow-up, sling procedures are an alternative to the artificial urinary sphincter implantation *(LEVEL OF EVIDENCE IV)*.

Resorbable or non-resorbable bulking agents might play some role in the treatment of neurogenic urinary incontinence *(LEVEL OF EVIDENCE IV)*.

E. Surgery to circumvent the bladder

Although less frequently used, after failure of more conservative treatment in patients with neurogenic bladder, continent or non continent urinary diversion represents an acceptable treatment for selected cases of neurogenic voiding dysfunction patients *(LEVEL OF EVIDENCE IV)*.

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