



Pickering, A. E., & McCabe, C. S. (2014). Prolonged ketamine infusion as a therapy for complex regional pain syndrome: Synergism with antagonism? *British Journal of Clinical Pharmacology*, 77(2), 233-238. [3992840]. <https://doi.org/10.1111/bcp.12157>

Peer reviewed version

Link to published version (if available):  
[10.1111/bcp.12157](https://doi.org/10.1111/bcp.12157)

[Link to publication record in Explore Bristol Research](#)  
PDF-document

## University of Bristol - Explore Bristol Research

### General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:  
<http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/>

Commentary on Niesters *et al* 2013.

Prolonged ketamine infusion as a therapy for Complex Regional Pain Syndrome:  
Synergism with antagonism?

Anthony E. Pickering<sup>1</sup> & Candida S. McCabe<sup>2</sup>

1- School of Physiology & Pharmacology, Medical Sciences Building, University of  
Bristol, BS8 1TD ; 2- Faculty of Health and Life Sciences , University of the West  
of England, Bristol.

Keywords : Ketamine, Complex regional pain syndrome, Neuropathic pain, NMDA  
receptor.

Abbreviations: NMDA – N-methyl-D-Aspartate ; CRPS – Complex Regional Pain  
Syndrome

"All authors have completed the Unified Competing Interest form at [www.icmje.org/coi\\_disclosure.pdf](http://www.icmje.org/coi_disclosure.pdf)  
(available on request from the corresponding author) and declare: no support from any organisation  
for the submitted work; no financial relationships with any organisations that might have an interest in

---

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/bcp.12157

the submitted work in the previous 3 years no other relationships or activities that could appear to have influenced the submitted work"

## Abstract

Complex regional pain syndrome (CRPS) remains a troubling and often refractory pain condition for which the existing treatments are inadequate. The review by Niesters et al in this journal highlights the interesting findings of several recent studies of the NMDA receptor antagonist ketamine in the treatment of CRPS. These studies report a robust analgesic effect that outlasts the period of infusion by weeks. However set against these positive findings are the issues presented by Ketamine pharmacokinetics, side effects and also the observation that these analgesic benefits are not mirrored by improvements in function or affect. In this commentary we consider the wider perspective of the potential for developing and evaluating this sort of NMDA antagonist therapy for the long-term management of CRPS patients.

Complex regional pain syndrome (CRPS) remains a troubling and often refractory pain condition that typically develops following either injury to a peripheral nerve (type II) or following trauma without obvious peripheral nerve damage (type I). It presents with a characteristic constellation of sensory, motor, autonomic and vascular signs within which pain is the central feature. Its aetiology is uncertain [1] and there is an ongoing debate about whether it is primarily a neuropathic or an inflammatory/auto-immune condition [2].

The existing data from treatment trials conventional analgesics, anti-neuropathic pain medications or nerve blocks have been largely disappointing [3, 4] and much of the emphasis in treatment is on functional rehabilitation (see the recent Royal College of Physicians treatment guidelines [5]). The limitations of existing treatments means that a substantial cohort of CRPS patients (~15,000 new cases per year in the UK based on the incidence figures of de Mos, de Bruijn [6]) is left with refractory, long-term severe pain causing significant disability. Consequently there is a need to develop innovative treatment approaches such as graded motor imagery, mirror visual feedback, spinal cord stimulation and trans-cranial magnetic stimulation all of which have shown some utility in clinical trials. Set within this context the review of *Niesters et al* within this *Journal* is timely, and articulates the arguments for a role of prolonged ketamine infusion in the management of neuropathic pain and specifically for CRPS.

### ***Ketamine***

Ketamine is an anaesthetic drug that has caused polarising tumult ever since its successful introduction to clinical practice in 1970 (reviewed by Domino [7]). Ketamine immediately found a role in battlefield anaesthesia during the Vietnam conflict where its safety (because of relative lack of cardio-respiratory depressant effects) and its

Accepted Article

analgesic properties were advantageous. It was the first of the class of “dissociative” anaesthetic agents and has remained an integral part of the clinical anaesthetic armamentarium for emergencies, for paediatrics and as a component of sedation for invasive medical procedures [8]. Since its introduction during the Vietnam conflict it has also been a drug of abuse, taken for its hallucinogenic and euphoric actions (like PCP). Within this setting it causes both morbidity (e.g. bladder pathology) and mortality through overdose related aspiration or psychotic delusions leading to self harm [9].

The main molecular mechanism of action of ketamine was uncovered when it was found to be an antagonist at the NMDA class of glutamate receptor [10]. The then recently identified NMDA receptor was rapidly realised to be a molecular coincidence detector for neurones (fitting with the Hebbian postulate) forming a key player in pathways for synaptic plasticity, learning and memory [11]. Ketamine is a non-competitive, use-dependent, NMDA channel blocker that could prevent the induction of synaptic potentiation. It was also subsequently realised that NMDA receptors play a central role in the processes of induction and maintenance of pain sensitisation - accounting for the analgesic efficacy of ketamine [12]. Although ketamine undoubtedly has actions at other relevant sites including nicotinic and opioid receptors, as well as via monoamine reuptake transporters, it is likely that both the anaesthetic and analgesic actions of ketamine are largely mediated by NMDA receptor antagonism [13]. Likewise the psychotropic and sympatho-excitatory side effects of ketamine are also predominantly mediated through NMDA receptor blockade.

From its earliest clinical use there has been considerable interest in exploring the therapeutic potential of ketamine in new territories. It was used to experimentally model schizophrenia where its propensity (like PCP) to cause hallucinations and

delirium was employed in human studies [14]. The recognition of its neuroprotective action led industry to use it as a template to develop other non-competitive NMDA antagonists to treat the excitotoxicity of stroke, head injury and also chronic neurodegenerative conditions [15]. Although animal studies with pre-emptive administration of these NMDA antagonists supported a neuroprotective action, the subsequent clinical studies have failed to identify a significant benefit in most trials. Concerns have also arisen over potential neurotoxic actions of ketamine seen in some animal studies. Nonetheless a similar rationale for the use of memantine (another non-competitive NMDA antagonist) in Alzheimer's disease has seen the drug licenced for clinical use as it can modify the progression of dementia [16].

Most recently ketamine has attracted attention because it can produce an improvement in depressive symptoms in man after acute administration [17]. These antidepressant actions are causing a stir in the field because of the rapid onset of therapeutic effect (unique amongst the currently available medications) which may enable its use as an acute treatment of severe depression. Reverse translational studies in animals have suggested that this beneficial effect is the product of rapid synapse formation (within hours) within the cortex - reversing the loss in synapse numbers seen in depression [18]. However, it is thought that ketamine is unlikely to be a suitable therapeutic agent in the longer-term treatment of depression because of its challenging pharmacokinetics and psychotomimetic side effects. Hence the search is currently underway for a better-tolerated NMDA antagonist that might be as efficacious for long term administration in depression [19].

### **The role of ketamine in pain management.**

Ketamine has an established place in the perioperative management of acute pain (at sub-anaesthetic doses <0.5mg/kg) where it has consistently been shown to be opioid sparing, to decrease nausea and vomiting while adding only a mild side-effect profile of its own [20]. The S(+) stereoisomer of ketamine has been shown to be twice as potent as an analgesic (mirroring its greater potency at the NMDA receptor). Ketamine acts by a distinct synergistic route to opioids and has also been suggested to attenuate the development of opioid tolerance [21] and perhaps to prevent opioid-induced hyperalgesia. It therefore has an accepted role in balanced analgesic regimes and is deployed in cases where perioperative pain control is likely to be challenging.

A significant body of evidence has tested the attractive hypothesis that pre-emptive administration of ketamine might prevent the development of pain (both acute and chronic) by preventing the sensitisation of neuronal circuits. Although positive findings were reported from animal studies, the data from human trials has not shown a clear pre-emptive benefit [22]. However, the acute analgesic effects of ketamine can outlast the expected half-life of the drug suggesting that there may indeed be some suppression of neural sensitisation in pain circuits [23].

Ketamine has also been employed in the treatment of chronic pain (particularly neuropathic pain) where it shows some short-term efficacy for refractory pain. However, its utility for chronic pain has been limited by its pharmacokinetics and side effect profile. It has relatively poor bioavailability after oral dosing and its short duration of action makes intermittent parenteral dosing impractical. Additionally the psychotomimetic profile, nausea and vomiting, sympatho-activation and effects on cognitive function allied to risks of misuse and dependence give it a narrow therapeutic window. This has prompted efforts to explore the role of other NMDA antagonists with either better pharmacokinetics or NMDA receptor subtype selectivity but these efforts

have yet to yield a convincing alternative therapy. A recent meta-analysis of therapeutics for neuropathic pain did not find sufficient evidence to support a role for ketamine or the other NMDA antagonists [24].

### **The role of ketamine in the treatment of Complex Regional Pain Syndrome**

Despite these issues several research groups have undertaken RCTs and published thought provoking papers on the use of prolonged ketamine infusions for treatment of refractory CRPS [25, 26]. These researchers rationalize this approach on the basis that there may be a longer lasting resetting of sensitised nociceptive circuits that can outlast the period of infusion (like that seen in acute pain [23]). The infusions were maintained at a sub-anaesthetic level and were either intermittently dosed over a 10 day period on an outpatient basis [25] or as a 5 day in-patient protocol [26]. These studies are credit-worthy as they have produced interesting affirmative findings and will have been challenging to undertake in a severe CRPS patient population. The analysis of these studies suggests that the prolonged infusions can produce reductions in pain that persist for weeks. Although issues with the quality of one of these trials [25] have been raised (see [27]) there would appear to be evidence of a substantial (>50%) analgesic effect that could be worthwhile in refractory cases of CRPS if its duration could be prolonged.

In a balanced consideration of these trials it should be recognised that CRPS is a significant clinical problem with limited therapeutic options [5, 28]. Any interventions capable of producing a lasting improvement in pain, motor function and disability merits serious consideration – and there are anecdotal reports suggesting that ketamine infusions are being deployed by pain clinicians globally for the treatment of a variety of pains including CRPS. This raises the overarching question of whether this ketamine

therapy can yet be advocated as an evidence-based, cost-effective, rational, safe and practicable therapy for CRPS?

Recent systematic reviews of treatments for neuropathic pain have not supported the use of any NMDA antagonist (e.g. [24]). However, CRPS type I is no longer considered to be a neuropathic pain syndrome according to the IASP definition [29]. Prolonged ketamine infusion has been included in the list of potential therapeutic options for the management of CRPS in the UK and Dutch guidelines with both documents rating the evidence for this treatment as 'moderate' or 'level 3' [4, 5, 30] but the guidelines conclude that there is insufficient evidence to commend ketamine (amongst other drugs) as a part of routine pain clinical practice for the management of CRPS. This in part reflects the relatively short term analgesic benefit, the requirement for repeated, prolonged hospital treatment along with the lack of improvement in affect or in functional capacity allied to enduring concerns about side effects.

The beneficial effects of the ketamine infusion on pain scores are lost by 12 weeks which must be set against the chronicity of the disease. Thus repeated dosing would be needed for patients with CRPS. For these parenteral infusion protocols this will require hospitalisation, close observation and will have a cost implication - to date no cost benefit analysis has been published. An additional complication is that prolonged infusion of ketamine is known to cause hepatic dysfunction (see review [31]). This came to light when half of the subjects in a trial of repeated courses of ketamine infusions for CRPS developed elevated liver enzymes [32] resulting in the study being halted early. Although these elevations were slowly reversible it clearly raises concerns about the safety of repeated dosing. It is also worth noting that liver toxicity has been reported in ketamine abusers and this raises the spectre that the other side effects whether psychotomimetic, urinary or cognitive seen in recreational users [9] would

also become problematic in patients undergoing chronic ketamine treatment (see review [33]).

There is a suggestion from the authors (and see [34]) that prolonged dosing with ketamine may provide a greater likelihood of therapeutic benefit. This principle has been somewhat contentiously extended to the territory of prolonged ketamine coma (involving patients spending days anaesthetised and ventilated on an intensive care unit) which its advocates claim to be able to “cure” chronic neuropathic pain – as yet only supported by case reports and open label, uncontrolled trials [35, 36]. Ketamine coma (and indeed oral ketamine and ketamine combined with nerve block) is cited in the UK Guidance document under ‘Experimental research’ with insufficient evidence for their efficacy at present (Goebel *et al.*, 2012) and are not included in the Dutch guidelines [30]. There are few centres or clinicians that would offer (on the available evidence) this as a reasonable therapeutic approach to the management of CRPS.

This need for chronic NMDA antagonist dosing also raises the issue of whether parenteral ketamine is the optimum drug for this purpose. An oral lozenge preparation of ketamine has been shown to have adequate pharmacokinetics [37] but is as yet unproven in any pain trial. Other studies of dosing with other NMDA antagonists like memantine and amantadine have failed to show beneficial effects alone [3, 4]. Case reports and a single study have reported some utility when memantine is used in combination with morphine and physical rehabilitation [38, 39] although this may reflect an opiate sparing effect, or the benefit of physiotherapy techniques, rather than an analgesic action in its own right.

The apparent comparative lack of effectiveness of these other NMDA antagonists in CRPS may relate to their lower efficacy as antagonists or may also indicate that the ketamine is acting via another molecular mechanism. Niesters *et al.* have started to

investigate this possibility further looking at influences on endogenous pain modulation and in imaging studies. Ketamine administration produces brain activations in areas that are part of pain modulation circuitry like the anterior cingulate, the insula and the brainstem and they report an increase in conditioned pain modulation in behaviour studies in volunteers (although they have also previously reported a suppression of another endogenous analgesic mechanism by ketamine - DNIC [40]). These effects could potentially also be mediated via opioidergic or monoaminergic reuptake action of ketamine. Such actions to engage / modulate endogenous analgesia might also help to account for the long duration ketamine effect as this could potentially be self-reinforcing.

One of the most striking features of the ketamine infusion studies is the lack of improvement of mood or function despite the improvement in pain scores. This is surprising given the recent realisation that ketamine exerts an antidepressant action [17]. It also runs counter to the belief that the functional deficits in CRPS are exclusively secondary to pain. This is more consistent with the idea that the motor disturbance is a separate pathological entity. It is also perhaps relevant that acute ketamine dosing is known to cause ataxia and motor impairment. Importantly the current guidelines for the management of CRPS recommend an integrated interdisciplinary approach to the patient's care which aims to reduce pain, restore function and improve quality of life [5, 28, 41]. Functional rehabilitation is at the centre of the care pathway and should be facilitated by education/self-management strategies, psychological and pharmacological support. Specifically, the risk/benefit profile of pharmacological interventions should be considered to ensure they do not compromise engagement with functional rehabilitation, as for example the excessive drowsiness that can be seen with opioids. Both of these ketamine infusion studies had cohorts with long disease

Accepted Article  
durations and therefore secondary psychosocial consequences of pain are likely to have been prevalent. Future research is warranted to establish what added benefit ketamine could provide within a multi-disciplinary rehabilitation model with administration earlier in the disease progression.

Administering ketamine as an adjunct to physical therapies may also be advantageous (besides its analgesic action) because of the potential for increased cortical synaptic plasticity being ascribed to NMDA antagonists from the depression field. Notably, memantine was reported to facilitate reversal of cortical reorganisation (in one subject) of the primary somatosensory map representing the painful CRPS limb [39]. Similar reports have been described for amputee phantom limb pains (PLP) when memantine has been administered [42]. It is well established in PLP and CRPS, that there is a correlation between levels of perceived pain intensity and the extent of cortical reorganisation, with pain reducing as cortical maps normalise [42, 43]. Changes in the primary sensory and motor maps in CRPS are thought to contribute to disrupted motor planning, altered sensory perceptions, referred sensations and body perception disturbances (see [44] for review). All of these clinically observed problems have shown some improvement with non-pharmacological strategies that have targeted correction but perhaps these benefits could be further enhanced in the presence of NMDA antagonists.

The ketamine infusion studies have provided evidence of a clinically meaningful (albeit transitory) analgesic benefit – something that is all too rare in the pharmacological management of CRPS. However the challenges posed by its pharmacokinetics and risk profile remain. The prospects for achieving similar outcomes using (hopefully) safer more convenient subtype selective NMDA antagonists remains on the horizon [13, 45] but for the present we have little evidence for effective

alternatives. Perhaps we will need a change of mind set to consider the management of CRPS with ketamine as being akin to the management of cancer with chemotherapy - toxic but if the outcome is sufficiently positive then it may justify the risks. To arrive at this point we would need multi-centre, RCTs comparing best current management +/- ketamine infusion with long term follow up and outcomes (as per IMMPACT guideline [46]) judged on the basis of remission and survivor analysis balanced against the toxicity. The situation is therefore similar for other potential new therapies such as spinal cord stimulation or intravenous immunoglobulins - a balance of risk versus benefit. The evidence discussed above indicates that even after 40 years the ketamine tiger (to paraphrase Domino [7]) remains potent and still has teeth that merit a cautious approach - to its use in the management of chronic pain.

## References

1. Bruehl S. An update on the pathophysiology of complex regional pain syndrome. *Anesthesiology* 2010; 113: 713-25.
2. Naleschinski D, Baron R. Complex regional pain syndrome type I: neuropathic or not? *Current pain and headache reports* 2010; 14: 196-202.
3. Rowbotham MC. Pharmacologic management of complex regional pain syndrome. *The Clinical journal of pain* 2006; 22: 425-9.
4. Cossins L, Okell RW, Cameron H, Simpson B, Poole HM, Goebel A. Treatment of complex regional pain syndrome in adults: A systematic review of randomized controlled trials published from June 2000 to February 2012. *European journal of pain* 2013; 17: 158-73.
5. Goebel A, Barker C, Turner-Stokes L, *al. e.* Complex regional pain syndrome in adults: UK guidelines for diagnosis, referral and management in primary and secondary care. In, London: Royal College of Physicians, 2012.
6. de Mos M, de Bruijn AG, Huygen FJ, Dieleman JP, Stricker BH, Sturkenboom MC. The incidence of complex regional pain syndrome: a population-based study. *Pain* 2007; 129: 12-20.
7. Domino EF. Taming the ketamine tiger. 1965. *Anesthesiology* 2010; 113: 678-84.
8. Hirota K, Lambert DG. Ketamine: its mechanism(s) of action and unusual clinical uses. *British journal of anaesthesia* 1996; 77: 441-4.
9. Kalsi S, Wood D, Dargan P. The epidemiology and patterns of acute and chronic toxicity associated with recreational ketamine use. *Emerging Health Threats Journal* 2011; 4: 1-10.
10. Anis NA, Berry SC, Burton NR, Lodge D. The dissociative anaesthetics, ketamine and phencyclidine, selectively reduce excitation of central mammalian neurones by N-methyl-aspartate. *British journal of pharmacology* 1983; 79: 565-75.
11. Collingridge GL, Bliss TV. Memories of NMDA receptors and LTP. *Trends in neurosciences* 1995; 18: 54-6.
12. Davies SN, Lodge D. Evidence for involvement of N-methylaspartate receptors in 'wind-up' of class 2 neurones in the dorsal horn of the rat. *Brain research* 1987; 424: 402-6.
13. Chizh BA. Low dose ketamine: a therapeutic and research tool to explore N-methyl-D-aspartate (NMDA) receptor-mediated plasticity in pain pathways. *Journal of psychopharmacology* 2007; 21: 259-71.
14. Javitt DC, Zukin SR. Recent advances in the phencyclidine model of schizophrenia. *The American journal of psychiatry* 1991; 148: 1301-8.
15. Muir KW. Glutamate-based therapeutic approaches: clinical trials with NMDA antagonists. *Current opinion in pharmacology* 2006; 6: 53-60.
16. Reisberg B, Doody R, Stoffler A, Schmitt F, Ferris S, Mobius HJ, Memantine Study G. Memantine in moderate-to-severe Alzheimer's disease. *The New England journal of medicine* 2003; 348: 1333-41.

17. Zarate CA, Jr., Singh JB, Carlson PJ, Brutsche NE, Ameli R, Luckenbaugh DA, Charney DS, Manji HK. A randomized trial of an N-methyl-D-aspartate antagonist in treatment-resistant major depression. *Archives of general psychiatry* 2006; 63: 856-64.
18. Duman RS, Aghajanian GK. Synaptic dysfunction in depression: potential therapeutic targets. *Science* 2012; 338: 68-72.
19. Dolgin E. Rapid antidepressant effects of ketamine ignite drug discovery. *Nature medicine* 2013; 19: 8.
20. Bell RF, Dahl JB, Moore RA, Kalso E. Perioperative ketamine for acute postoperative pain. *Cochrane database of systematic reviews* 2006: CD004603.
21. Hirota K, Lambert DG. Ketamine: new uses for an old drug? *British journal of anaesthesia* 2011; 107: 123-6.
22. Moiniche S, Kehlet H, Dahl JB. A qualitative and quantitative systematic review of preemptive analgesia for postoperative pain relief: the role of timing of analgesia. *Anesthesiology* 2002; 96: 725-41.
23. McCartney CJ, Sinha A, Katz J. A qualitative systematic review of the role of N-methyl-D-aspartate receptor antagonists in preventive analgesia. *Anesthesia and analgesia* 2004; 98: 1385-400, table of contents.
24. Finnerup NB, Sindrup SH, Jensen TS. The evidence for pharmacological treatment of neuropathic pain. *Pain* 2010; 150: 573-81.
25. Schwartzman RJ, Alexander GM, Grothusen JR, Paylor T, Reichenberger E, Perreault M. Outpatient intravenous ketamine for the treatment of complex regional pain syndrome: a double-blind placebo controlled study. *Pain* 2009; 147: 107-15.
26. Sigtermans MJ, van Hilten JJ, Bauer MC, Arbous MS, Marinus J, Sarton EY, Dahan A. Ketamine produces effective and long-term pain relief in patients with Complex Regional Pain Syndrome Type 1. *Pain* 2009; 145: 304-11.
27. Bell RF, Moore RA. Intravenous ketamine for CRPS: Making too much of too little? *Pain* 2010; 150: 10-1.
28. Harden RN, Swan M, King A, Costa B, Barthel J. Treatment of complex regional pain syndrome: functional restoration. *The Clinical journal of pain* 2006; 22: 420-4.
29. Jensen TS, Baron R, Haanpaa M, Kalso E, Loeser JD, Rice AS, Treede RD. A new definition of neuropathic pain. *Pain* 2011; 152: 2204-5.
30. Perez RS, Zollinger PE, Dijkstra PU, Thomassen-Hilgersom IL, Zuurmond WW, Rosenbrand KC, Geertzen JH, force Clt. Evidence based guidelines for complex regional pain syndrome type 1. *BMC neurology* 2010; 10: 20.
31. Sear JW. Ketamine hepato-toxicity in chronic pain management: another example of unexpected toxicity or a predicted result from previous clinical and pre-clinical data? *Pain* 2011; 152: 1946-7.
32. Noppers IM, Niesters M, Aarts LP, Bauer MC, Drewes AM, Dahan A, Sarton EY. Drug-induced liver injury following a repeated course of ketamine treatment for chronic pain in CRPS type 1 patients: a report of 3 cases. *Pain* 2011; 152: 2173-8.
33. Bell RF. Ketamine for chronic noncancer pain: concerns regarding toxicity. *Current opinion in supportive and palliative care* 2012; 6: 183-7.
34. Noppers I, Niesters M, Aarts L, Smith T, Sarton E, Dahan A. Ketamine for the treatment of chronic non-cancer pain. *Expert opinion on pharmacotherapy* 2010; 11: 2417-29.

35. Koffler SP, Hampstead BM, Irani F, Tinker J, Kiefer RT, Rohr P, Schwartzman RJ. The neurocognitive effects of 5 day anesthetic ketamine for the treatment of refractory complex regional pain syndrome. *Archives of clinical neuropsychology : the official journal of the National Academy of Neuropsychologists* 2007; 22: 719-29.
36. Kiefer RT, Rohr P, Ploppa A, Dieterich HJ, Grothusen J, Koffler S, Altemeyer KH, Unertl K, Schwartzman RJ. Efficacy of ketamine in anesthetic dosage for the treatment of refractory complex regional pain syndrome: an open-label phase II study. *Pain medicine* 2008; 9: 1173-201.
37. Chong C, Schug SA, Page-Sharp M, Jenkins B, Ilett KF. Development of a sublingual/oral formulation of ketamine for use in neuropathic pain: Preliminary findings from a three-way randomized, crossover study. *Clinical drug investigation* 2009; 29: 317-24.
38. Gustin SM, Schwarz A, Birbaumer N, Sines N, Schmidt AC, Veit R, Larbig W, Flor H, Lotze M. NMDA-receptor antagonist and morphine decrease CRPS-pain and cerebral pain representation. *Pain* 2010; 151: 69-76.
39. Sinis N, Birbaumer N, Gustin S, Schwarz A, Bredanger S, Becker ST, Unertl K, Schaller HE, Haerle M. Memantine treatment of complex regional pain syndrome: a preliminary report of six cases. *The Clinical journal of pain* 2007; 23: 237-43.
40. Niesters M, Dahan A, Swartjes M, Noppers I, Fillingim RB, Aarts L, Sarton EY. Effect of ketamine on endogenous pain modulation in healthy volunteers. *Pain* 2011; 152: 656-63.
41. Stanton-Hicks MD, Burton AW, Bruehl SP, Carr DB, Harden RN, Hassenbusch SJ, Lubenow TR, Oakley JC, Racz GB, Raj PP, Rauck RL, Rezai AR. An updated interdisciplinary clinical pathway for CRPS: report of an expert panel. *Pain practice : the official journal of World Institute of Pain* 2002; 2: 1-16.
42. Flor H. Cortical reorganisation and chronic pain: implications for rehabilitation. *Journal of rehabilitation medicine : official journal of the UEMS European Board of Physical and Rehabilitation Medicine* 2003: 66-72.
43. Maihofner C, Handwerker HO, Neundorfer B, Birklein F. Cortical reorganization during recovery from complex regional pain syndrome. *Neurology* 2004; 63: 693-701.
44. Bailey J, Nelson S, Lewis J, McCabe CS. Imaging and Clinical Evidence of Sensorimotor Problems in CRPS: Utilizing Novel Treatment Approaches. *Journal of neuroimmune pharmacology : the official journal of the Society on NeuroImmune Pharmacology* 2012.
45. Chizh BA, Headley PM. NMDA antagonists and neuropathic pain--multiple drug targets and multiple uses. *Current pharmaceutical design* 2005; 11: 2977-94.
46. Dworkin RH, Turk DC, Farrar JT, Haythornthwaite JA, Jensen MP, Katz NP, Kerns RD, Stucki G, Allen RR, Bellamy N, Carr DB, Chandler J, Cowan P, Dionne R, Galer BS, Hertz S, Jadad AR, Kramer LD, Manning DC, Martin S, McCormick CG, McDermott MP, McGrath P, Quessy S, Rappaport BA, Robbins W, Robinson JP, Rothman M, Royal MA, Simon L, Stauffer JW, Stein W, Tollett J, Wernicke J, Witter J, Impact. Core outcome measures for chronic pain clinical trials: IMMPACT recommendations. *Pain* 2005; 113: 9-19.