EDITOR'S CHOICE

Use of the human dive reflex for the management of supraventricular tachycardia: a review of the literature

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ABSTRACT

Background The human dive reflex (HDR), a physiological phenomenon similar to the bradycardia reflex used by marine mammals during prolonged submersion, can be employed in managing paroxysmal supraventricular tachycardia (PSVT). This review aims to identify a standardised HDR technique for haemodynamically stable PSVT, to determine the effectiveness of the HDR and to define its usefulness in the prehospital setting.

Methods A review of the Medline, EMBASE and CINAHL databases was conducted. Articles were included if they described the use of the HDR to revert PSVT in the prehospital or emergency medical setting, the nature of the effectiveness of the HDR for PSVT or historically significant developments of HDR techniques for PSVT reversion. Articles not available in English or describing the use of HDR in animal studies only were excluded.

Results 211 articles were identified, of which 21 were found to be relevant. These included 10 studies of HDR effectiveness in PSVT and three physiological studies of HDR effect. No standardised model of performance exists for the HDR. Elements of performance include: a cold stimulus applied to the entire face, a specific temperature of the cold stimulus, application duration, breath holding during HDR and posture assumed to perform the procedure. There are also safety and logistics issues with using the HDR in prehospital care.

Conclusions The HDR represents an effective method of terminating PSVT in the hospital emergency department. Its usefulness in prehospital care requires further evaluation of the elements of the manoeuvre to determine appropriateness to this setting.

BACKGROUND

The dive reflex was originally observed in aquatic animals, specifically seals. It is a cardiovascular reflex, mediated through increased vagal tone, that results in more efficient oxygen utilisation and a slower heart rate while ensuring adequate cerebral perfusion (through maintenance of mean arterial pressure) and redistribution of core blood flow.[1–3] When precipitated in humans by immersion in cold water, the human dive reflex (HDR) primarily results in a reflex bradycardia response.[4 5] This bradycardia, and an associated increase in myocardial refractoriness, can be harnessed in a simple and non-invasive manoeuvre for the termination of paroxysmal supraventricular tachycardia (PSVT).

The HDR manoeuvre in humans has resulted from applying the concept of cold induced bradycardia (stimulation of thermoregulatory sensors in the skin triggering increased vagal tone) to the reversion of PSVT through prolonged myocardial refractoriness.[1–3] Studies have demonstrated that immersion of the face only is sufficient to elicit this reflex in human subjects.[1 2 6 7] Hence the simplicity of facial immersion to elicit the HDR is useful in providing increased vagal tone for PSVT management. Increases in vagal tone above that generated by the HDR alone have been reported when subjects performing the manoeuvre also employed deep inhalation and breath holding, which provoked a mild bradycardia.[1 2 4 6] This is due to stimulation of baroreceptors in the carotid bodies and aortic arch, which triggers an increase in vagal tone (a reflex common to both the Valsalva manoeuvre and the carotid sinus massage techniques[8–10]). It is likely that the combination of breath holding and cold stimulus provides the HDR with an increased effect for PSVT termination; however, this is yet to be quantified in clinical studies.

Use of the HDR for the reversion of haemodynamically stable PSVT has been advocated since the early 1970s.[1–3 5–9 11–13] However, use of the HDR in the prehospital setting is a relatively recent adaptation from emergency medicine practice, providing a simple management strategy for patients with regular narrow complex tachyarrhythmias.

Although the HDR has gained acceptance for the treatment of PSVT within international resuscitation guidelines,[14–16] a standard approach with maximum effectiveness has not been described. Consequently, this review aims to identify a standardised technique to elicit HDR for the management of haemodynamically stable PSVT, to determine the effectiveness of the HDR for termination of PSVT and to define the suitability of the HDR for prehospital emergency care practice.

METHODS

A comprehensive search strategy was developed, incorporating both the peer reviewed and non-peer reviewed literature, and was based on the Cochrane Prehospital Search Filter V.2.0.[17] This was used to search the electronic databases Medline (1948 to October 2011), EMBASE (1966 to October 2011), CINAHL (1937 to October 2011), the Cochrane Library of Systematic Reviews and the Cochrane Database of Abstracts of Reviews of Effects (DARE). In addition, the reference sections of articles identified were scrutinised and relevant papers examined.

The following key terms were used in the search strategy: dive reflex, human dive reflex, diving reflex, paramedic, ambulance, emergency medical technician, emergency medicine, tachyarrhythmia, supraventricular tachycardia, paroxysmal supraventricular tachycardia, atrioventricular nodal re-entrant tachycardia and atrioventricular re-entrant tachycardia.

Articles were included if they discussed use of the HDR to revert PSVT in humans of any age in the prehospital or emergency medicine setting. Articles were also included if they described specific attributes or the nature of effectiveness of the HDR on regular narrow complex tachyarrhythmias, or the historical significance of the development of knowledge of HDR therapies for regular narrow complex tachyarrhythmia reversion.

Articles were excluded if they were not available in English or described the use of HDR in animal studies only.

RESULTS

A total of 211 articles were identified during the search and none reported investigations undertaken in the prehospital setting. After cross referencing to eliminate duplications and sorting the results according to technique, effectiveness and application, 21 articles were selected for further analysis (figure 1). Ten clinical studies were found to be of relevance, as they dealt specifically with the use of the HDR in the management of PSVT (table 1).[1 2 4 6 8 9 13 18] Three physiological studies were also identified which assist in defining responses to the HDR in healthy subjects.[4 8 18] A single review article provided a description of the elements of the HDR which may be quantified within a standardised model of application.[19]

The techniques used to elicit the HDR varied greatly, comprising five essential elements:

- A cold stimulus applied to the entire face.
- A specific temperature of the cold stimulus.
- A duration of application.
- Breath holding during performance of the HDR.
- A posture assumed to perform the procedure.

A single review article suggested a method for optimising the HDR response for the management of PSVT.[19] The authors described the elements of the HDR (as above), and also included 'emotion' as a component of effectiveness. This element focuses on the nature of increased sympathetic response to anxiety, and encourages a quiet and calm patient prior to commencement of the procedure. Many of the aspects of the suggested HDR technique were taken from physiological studies and require examination within clinical studies using patients with PSVT to quantify effectiveness.

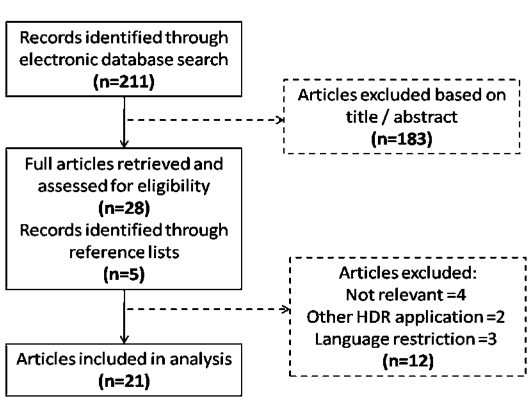

Figure 1 Search results. HDR, human dive reflex.

Table 1 Studies of the effectiveness of the human dive reflex in adult subjects presenting with supraventricular tachycardia

Author	Sample size	Age range (years)	Study type	'Cold' tool	Temperature (°C)	Apnoea employed	Duration (s)	Reversion success	History of previous SVT	Subject rhythm	HDR performance position
Wildenthal *et al*[2]	7	22–66	Prospective interventional, non-randomised	Cold water	2	Breath holding during facial immersion	15–35	85.7	Yes (4), No (3)	PAT	Sitting
Wayne[1]	10	10–53	Prospective interventional, non-randomised	Cold water	10	Breath holding during facial immersion	15–38	90	Not stated	PAT	Prone
Mehta *et al*[13]	35	16–69	Prospective interventional, non-randomised	Water	5–7	Breath holding during facial immersion	35	17	Yes	PSVT	Sitting
Wen *et al*[9]	133	14–72	Prospective interventional, non-randomised	Ice and water in plastic bag	Not stated	Not stated	20	5	Yes	PSVT	Supine

HDR, human dive reflex; PAT, paroxysmal atrial tachycardia; PSVT, paroxysmal supraventricular tachycardia; SVT, supraventricular tachycardia.

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Comparison of results is challenged by each identified study utilising a variety of cold stimuli at differing temperatures, with various postures and durations of application employed. The use of apnoea is common across techniques, although this is achieved through unavoidable obstruction of the mouth and nose by the cold stimulus rather than as an objective element of the technique. The results have identified studies where the aim was to determine HDR effectiveness in PSVT using subjects with arrhythmia, and also physiological studies of the impact of the HDR on healthy subjects in the absence of arrhythmia. These physiological studies are valuable in determining haemodynamic responses to the HDR, yet can only hint at the potential for PSVT reversion effectiveness using the HDR. Blinding of subjects and investigators to outcomes or procedures was not undertaken within any of the studies identified, presumably because of the impracticability of blinding both the therapist and patient to the procedure. Where stated in the original article, the diagnosis of PSVT for subjects within each study was made through medical examination and ECG confirmation of the arrhythmia.

Within the four adult studies listed in table 1, the HDR performance method varied considerably (duration between 15 and 38 s, cold stimulus between 2°C and 10°C where stated), as did patient age (10–69 years) and reversion effectiveness (5–90%). This range of effectiveness demonstrates the impact of small sample size and variation of elements of technique, and requires larger clinical studies with a standardised therapy to demonstrate an effect which would be useful in the clinical setting.

Six articles described reversion success and a specific side effect of the HDR in paediatric patients (table 2). Two articles described the reversion effect of HDR in three case studies, with reversion times ranging from 'immediate' to a maximum of 6 s post immersion in iced water.[3 20] A third case study described an incidence of cold burn injury sustained by a 4-day-old baby post ice pack application for performance of the HDR.[21] Two of the articles also described potential side effects such as apnoea, transient arrhythmias (sinus arrest, nodal and ventricular escape beats, and ventricular tachycardia), prolonged periods of sinus arrest or asystole.[2 6] The temperature of the cold stimulus used for the HDR was not stated in these articles.[3 20 21] The magnitude of vagal tone generated by the HDR was also not assessed in these studies, and consequently onset or severity of cardiovascular side effects is unpredictable. In response to this, one study suggested that the HDR should only be used where adequate resuscitation and monitoring facilities are available.[6]

Three physiological studies, which measured the effect of HDR on vagal tone using bradycardia as an outcome measure, also demonstrated a range of performance techniques. Table 3 highlights these variations of technique. Importantly, Furedy *et al*[2] demonstrated that a temperature of 10°C maximises the bradycardia effect. They also noted that a brief sympathetic response occurred during the initial 12 s period of the manoeuvre. However, it was the 12–40 s period of the manoeuvre that resulted in the most significant effect on heart rate, demonstrating mean bradycardia responses of 5–17 bpm, attributable to increased vagal tone.[8] This finding has implications for standardising performance of the HDR. The absence of a standardised technique and small sample sizes may account for the variance of reversion rates across the physiological studies examined. Arnold also demonstrated that HDR resulted in a greater bradycardia effect than other vagal manoeuvres although failed to quantify the impact of age on reversion success.[4]

Table 2 Studies of the effectiveness of the human dive reflex in paediatric subjects presenting with supraventricular tachycardia

Author	Sample size	Age range	Study type	'Cold' tool	Temperature (°C)	Apnoea method employed	Duration (s)	Reversion success (%)	History of previous SVT	Rhythm	HDR performance position
Bisset *et al*[6]	10	1 day–15 years	Prospective interventional, non-randomised	Ice and water in plastic bag	Not stated	Covered nose and mouth	1–15	100	Yes (5), No (5)	PSVT	Supine
Sreeram *et al*[5]	16	Birth-1 year	Retrospective case review	Iced water	Not stated	Apnoea consequent of complete facial immersion	5	89.8	Not stated	PAT	Not stated
Whitman *et al*[3]	1	8 years	Case study	Ice water	Not stated	Breath holding during facial immersion	'Instantaneous'	100	Yes	PSVT	Not stated
Whitman *et al*[20]	2	7 and 10 days (2 cases)	Case series	Ice and water	Not stated	Breath holding during facial immersion	6 and 4–5	100	Case 1: not stated, Case 2: yes	PSVT (both cases)	Not stated (both cases)
Craig *et al*[21]	1	14 days	Case study	Ice to face	Not stated	Not stated	Not stated	100	Yes	PSVT	Not stated
Sperandeo *et al*[23]	10	14 days–5 months	Prospective interventional, non-randomised	Iced water	4–5	Breath holding during facial immersion	6–7	100	Yes	PSVT	Not stated

HDR, human dive reflex; PAT, paroxysmal atrial tachycardia; PSVT, paroxysmal supraventricular tachycardia; SVT, supraventricular tachycardia.

Table 3 Physiological studies of the effectiveness of the human dive reflex in healthy subjects without arrhythmia

Author	Sample size	Age range (years)	Study type	'Cold' tool	Temperature (°C)	Apnoea employed	Duration (s)	History of previous SVT	Subject rhythm	HDR performance position
Arnold[4]*	58	10–71	Prospective, randomised to various vagal manoeuvres	Ice water in plastic bag or facial immersion	1	Covered nose and mouth or apnoea during facial immersion	30	No	SR	Supine
Kaijser *et al*[18]*	15	60–80	Mixed methods case control study	Iced water	Not stated	Breath holding during facial immersion	10	No	SR	Sitting
Furedy *et al*[8]*	48	Adults (>18 but not stated)	Prospective interventional, non-randomised	Water	10, 20, 40	Breath holding during facial immersion	40	No	SR	Prone

*These studies used bradycardia measured from resting heart rate as a clinical outcome measure to describe the magnitude of vagal tone in healthy subjects with no arrhythmia present.
HDR, human dive reflex; SR, sinus rhythm; SVT, supraventricular tachycardia.

Both paediatric specific clinical studies demonstrated reversion success in excess of 89.8% in subjects under 1 year of age.[5 6] It has been suggested that the HDR is a more acceptable technique for paediatric patients with PSVT. It involves less physical and emotional trauma through avoidance of invasive techniques (such as intravenous cannulation) and has a better compliance rate due to its simplicity.[6 20] However, the lack of detail provided within these articles prevents the identification of aspects of technique (specifically cold temperature tool) that may have assisted in improving the effect. None of the identified studies quantified the relationship between pre-excitation syndromes (such as Wolf–Parkinson–White or Lown–Ganong–Levine) and reversion effectiveness when using the HDR.

Kaijser and Sachs[18] demonstrated a significantly greater bradycardia response in subjects aged under 45 years versus those aged older than 60 years (<45 year age group: mean heart rate decrease 24 (SD 8), $p<0.05$; >60 year age group: mean heart rate decrease 11 (SD 7), $p<0.05$). This information supports the concept of improved reversion effectiveness in younger patients.

DISCUSSION

The use of vagal manoeuvres as a firstline treatment for PSVT in the prehospital setting provides an important and simple means of attempting initial termination of the arrhythmia. As a precursor to pharmacological agents, vagal manoeuvres may allow paramedics to avoid some of the significant side effects of drugs such as verapamil (hypotension) and adenosine (bronchospasm in the asthma patient) in the early stages of PSVT arrhythmia management.

The published literature demonstrates a range of HDR inducing techniques which essentially focus on providing a cold stimulus to the face in order to promote increased vagal tone. It is not possible to determine with any certainty, therefore, the best combination of cold tool (eg, water, ice bag), temperature and duration of the manoeuvre for PSVT reversion. Optimal stimulation of the HDR requires further study of the methodological elements to provide an evidence base for the technique.

The importance of posture in HDR performance is also of interest. The Valsalva manoeuvre uses supine posturing to protect against vagal mediated hypotension which could be expected if the subject were in an upright position. It is therefore important to ascertain the relationship between posture and effect (or onset of side effects) for the HDR, which to date has not been examined. Use of the HDR in the prehospital setting would require the use of a cold stimulus that is readily accessible, easy to use and that can withstand the moving environment of an ambulance. A bowl of water precludes itself from this setting, with electrical cardiac monitoring equipment and liquid providing an unacceptable risk to both paramedic and patient. The nature of patient movement in this environment, and the subsequent artefact generated on the ECG, would also be unacceptable in prehospital care.

The use of breath holding as a component of the HDR is one which also requires examination. The nature of the cold stimulus to the subject requires obstruction of the mouth and nose for the duration of the manoeuvre, yet there is no evidence to indicate the impact of the stage of the respiratory cycle on vagal tone (such as complete exhalation, deep inhalation or some neutral point in between). This may influence the effectiveness of the HDR due to the increased vagal tone generated by deep inspiration (and subsequent triggering of baroreceptors in the aortic arch and carotid bodies).

The temperature of the cold stimulus has been noted to affect physiological responses within the HDR as a temperature of

<5°C may stimulate pain fibres and a sympathetic response.[8 19 22] This would be counterproductive to the aim of the HDR as an antiarrhythmic therapy. Conversely, when the cold stimulus rises above 20°C, little effect is noted through reduced stimulation of the trigeminal nerve (and thus reduced vagal response).

The work of Furedy *et al*[8] has added value to the evaluation of the manoeuvre through studying the effect of water temperature on the effectiveness of the bradycardia response. However, their work raises new questions regarding the potential impact of ambient temperature (and its relationship to the cold stimulus generated during the manoeuvre) on effect in the clinical setting. Variation in ambient temperature is not usually an issue in the hospital setting. However, ambient temperature in the prehospital setting may vary considerably and the importance of this variable in this setting is unknown. Other prehospital specific requirements of the HDR include its appropriateness when used to manage PSVT patients in rural or remote areas. The long transport times associated with these areas suggest a need to provide a cold stimulus tool that can be maintained at a specific temperature (or replaced) over a prolonged period of time. This provides challenges in requiring a device which can demonstrate prolonged use, is cost effective and is able to be stored for long periods of time in a vehicle where temperatures may vary considerably according to season.

The paediatric studies indicate high success rates for this patient group. However, the use of cold stimulus and involuntary apnoea combined with patients whose age precludes appropriate discussion and understanding of the procedure would likely result in a heightened anxiety response or produce other side effects (such as apnoea and arrhythmias) and reduce the effectiveness of the HDR in this patient group. This point requires further investigation to determine the impact of emotion on effectiveness of the HDR in infants and young children with PSVT, as suggested by Gooden.[19] Careful assessment, including the use of 12 lead ECG to diagnose the arrhythmia, is required prior to contemplation of the use of vagal manoeuvres such as the HDR.

Across the 10 clinical studies, 18 patients required subsequent HDR interventions during the study for recurrent PSVT.[1–3 5 21 23] Prehospital management of PSVT (and indeed all other aspects of care) by paramedics is limited by statutory regulation and authority to practice. Thus even those patients successfully reverted to sinus rhythm using the HDR may require transport to hospital. This challenges the need to treat rather than transport and impacts on health system cost. Although studies have not clearly defined the harm of prolonged PSVT,[24–26] early termination serves to reduce patient discomfort, reduce hospital stay times following assessment and enables electrophysiology studies and further definitive procedures to be carried out if required. The value of 12 lead ECG in prehospital care also assists in later electrophysiological assessment within the hospital environment.

RECOMMENDATIONS

Due to the paucity of research in this area, only limited conclusions can be drawn regarding the use of the HDR in the prehospital setting. The studies reviewed suggest that a substantial HDR may be elicited by:

- Complete facial immersion, or coverage of the whole face by a cold pack.
- Breath holding during the manoeuvre.
- Water/cold pack temperature of 10°C (at room temperature of approximately 22°C).
- A duration of 30–40 s.

Also, the environment where the HDR is conducted should ideally be optimal for both the patient and the treating paramedic with regard to environment, equipment and hazard control. This would be a room with normal ambient temperature and adequate lighting, where continuous cardiac monitoring is available and the risk of electrical hazard is low. The provision of cardiac defibrillation and synchronised cardioversion equipment, oxygen and mechanical ventilation devices, and firstline resuscitation drugs should be a minimum standard for the procedure. This environment, albeit in a more rudimentary form, exists within the confines of many stationary ambulances. However, the nature of training and competency of the paramedic impacts on the overall safety of the procedure.

These essential elements do not suggest an evidence based standard but rather provide the basis for further study into the composition of the HDR to standardise the technique. The assessment of other variables such as posture, breath holding and ambient temperature will provide further detail to enable quantification of its usefulness in the prehospital setting. The effectiveness of the HDR to terminate PSVT has, within the reviewed studies, provided limited evidence with regard to prevention of recurrence of the arrhythmia. It would be prudent to suggest that subsequent HDR attempts may be required, and that these be attempted only after a restitution period consistent with other vagal manoeuvres (approximately 3 min) and physical examination to ensure that no injury has developed as a result of application of the cold stimulus.

LIMITATIONS

The ability to ascertain the effectiveness of the HDR is confounded by the range of techniques used to perform the manoeuvre, small sample sizes and potential for publication bias. Articles included in this review had large variations in performance components, including posture, duration, temperature of the cold stimulus and type of cold stimulus. The lack of standardisation of these elements of HDR technique limits comparison of results between studies.

CONCLUSION

Evidence relating specifically to the effectiveness of the HDR for termination of PSVT is limited. Notwithstanding this, it appears that complete facial immersion in iced water, or covering the face with an ice pack or cold stimulus of 10°C, for at least 30 s, may result in the best reversion rates until more evidence becomes available. Larger studies with appropriate sample sizes, standardised methods, specific age groups and examining the effects of ambient temperature would assist in evaluating the effectiveness of the HDR for use in the prehospital setting.

Competing interests None.

Contributors GS designed and conducted the search, compiled and analysed the results, and composed the manuscript. AM, DT and PC analysed the results, and edited and contributed to the manuscript. GS designed the search strategy, conducted the search, analysed the results and drafted the paper. AM reviewed the search strategy, results and draft paper, with input into style and content of each stage. DT reviewed the search strategy, results and draft paper, with input into style and content of each stage. PC reviewed the search strategy, results and draft paper, with input into style and content of each stage.

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