Chapter 1

The history of central venous access

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Introduction

Techniques and indications for venous access are rapidly changing with huge advances in the last 60 years. An appreciation of such developments and earlier historical endeavours in this field allow the reader insight into the origins of many modern-day practices and the devices in use.

The origins of venous access

Up to the time of William Harvey (1578–1657), there was considerable debate about the circulation. Shortly after Harvey's discovery, Sir Christopher Wren (1971) made the first attempts at providing intravenous nutrition and injecting drugs. In 1656, using a goose quill attached to a pig's bladder, he infused a mixture of wine, ale and opium into dogs. He was not alone in this field of inquiry, for Lower and King (1662), Lower (1932) and Major (1667) performed intravenous infusions and transfusions on animals. Major also used the silver cannula and a pig's bladder to infuse saline via the antecubital fossa veins in a human being. An illustration of this technique can be found in the Wellcome History of Medicine Museum in London. Robert Boyle described the work of Wren, and he performed experiments using intravenous infusion from animals to humans (Birch 1744, Wheatley 1966). Denys (1667) transfused blood from a lamb into a human being in 1667 in Paris, and Lower performed the first successful transfusion of animal blood into a human being in the same year. These practices soon fell into disrepute, as fatal reactions occurred. A church and parliamentary edict prevented further transfusions until 1818, when Blundell (1818), an English obstetrician, saved the lives of several patients with postpartum haemorrhage by injecting blood using a syringe.

In 1733, Stephen Hales conceived the idea of introducing a glass tube into the venous and arterial systems of a live mare in order to measure blood pressure. He also made

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the first attempts to estimate the cardiac output by bleeding the animal to death and filling its left ventricle with melted beeswax. He multiplied the volume of the solidified wax by the normal resting heart rate in order to achieve figures for the cardiac output of dogs, oxen, sheep and humans (Hales 1974).

Cardiac catheterisation was first performed by Claude Bernard in France to determine the temperature of the blood in the right and left ventricles. Hoff *et al.* (1965) had suggested that animal heat was produced as a result of respiratory gas exchange in the lungs, whilst Magnus (1837) had advanced the alternative hypothesis that 'combustion' took place in the tissues. In 1844, Bernard (1876) operated on a horse and cannulated the carotid artery and left ventricle, followed by the internal jugular vein and right ventricle, using a long mercury thermometer. He disproved the pulmonary combustion theory, and later he went on to measure intracardiac pressures using glass tubes. Bernard (1876) also noted in an autopsy on a dog that the right ventricle had been perforated by the tube, causing intrapericardial haemorrhage, and thus he recorded the first complication of central venous catheterisation. The thrust of these investigations was to try and determine why the living body was warm compared to the coldness of a corpse.

The first systemic study, description and interpretation of intracardiac pressure recordings were made by Chauveau and Marey (1863) after working at the School of Veterinary Medicine of Alfort near Paris. They developed a special double lumen catheter, and Marey wrote:

> *one can be reassured of the innocuity of this method by examining the horse, who is scarcely disturbed, walks and eats as usual. In only a few instances is the pulse rate slightly increased, especially at the time of the catheter's introduction within the heart cavities.*

Thus, he first noted the potential for arrhythmias to occur as a complication of insertion. He also emphasised the importance of extending the clinical examination to include the exploration of many cavities and canalicular systems with catheters; however, neither he nor Chauveau extended their investigations to humans. During the following years cardiac catheterisation developed rapidly as an investigation in circulatory physiology and new manometric systems were developed. Rolleston (1887) pointed out the role of friction along the tube from the exploring cannula to the manometer. Porter (1892) studied the canine heart using silver-plated brass tubes with a single or double lumen and an internal diameter of 3 mm, connected by a 30–40-cm-long rubber tubing with the same diameter as the manometer. At this time, arguments surrounded the question of whether or not such catheters and manometers accurately reflected the intracardiac pressures. These questions were finally resolved by Franck (1903, 1905) when he published his classic papers.

Controversy surrounds the earliest pioneers of central venous catheterisation in humans. Werner Forssmann, André Cournand and Dickinson Richards jointly shared the 1956 Nobel Prize for Medicine. The first to report the use of a catheter in humans for obtaining mixed venous blood for the measurement of right atrial pressure or cardiac output were Cournand and Ranges (1941). They mention Forssmann (1929) as the originator of central venous catheterisation technique. In 1929, shortly after the publication

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of Forssmann's paper in which he described his self-catheterisation experiment, an addendum was published in which Forssmann referred to a communication stating:

> *Professor E Unger informs me that Bleichroeder, Unger and Loeb carried out the same experiment in 1912. This was published under the title – 'Intra-arterielle Therapie'. He [Unger] had passed a ureteric catheter into the arm veins up to the axilla on four human subjects, among them Dr Bleichroeder, and also from the thigh to the vena cava. To judge from the length of the catheter and a stabbing pain, he believed that in the case of Dr Bleichroeder, the catheter must reach the right heart. This latter experiment was not published.*

The reference provided by Unger alluded to presentations by Bleichroeder, Unger and Loeb (1912) before the Hufeland Medical Society in Berlin. Bleichroeder reported in 1905 that he had passed catheters into the arteries and veins of dogs as well as of human beings. He did not believe the experiments to be of any practical value and left them unpublished. However, in 1912, with the opening of the 'chemotherapeutic era', he perceived a use for his method, as it was believed at the time that a chemotherapeutic agent should be applied as near as possible to the diseased organ. Thus, in four patients with puerperal sepsis, Bleichroeder and Unger inserted a catheter via the femoral artery up to the region of the aortic bifurcation and injected 'collargol'. In his address, Bleichroeder (1904) did not specify the nature of his experiments, but remarked that he had used the catheter to obtain blood from the inferior vena cava close to the hepatic vein. He was interested in the morbid anatomy of cirrhosis, and these investigations may have been related. In his paper concerning intra-arterial therapy, he stated that he had passed the catheter well over a hundred times through the femoral vein and left it in place for several hours without clot formation or other ill-effects. Naturally, he was unable to verify the exact position of catheters using contrast radiology.

Forssmann (1931) conceived the idea of introducing a catheter into the right heart in order to administer emergency drugs on the operating table, in the most rapid and effective way, during episodes of sudden cardiac failure. He was opposed to percutaneous intracardiac injections because of the risks of cardiac tamponade, from either a coronary vessel laceration caused by the needle or leakage of blood from the heart itself, and of pneumothorax from pleural laceration. He first attempted the approach on cadavers using a vein in the antecubital fossa of the left arm. He chose the left arm because the catheter had to make less of a curve when it passed through the subclavian and innominate veins. He also realised that this occurred because of the relatively acute angle at which various tributaries entered the main brachial, axillary and subclavian veins, pointing always in the direction of blood flow.

At the time, Forssmann was working in the small town of Eberswalde, 50 miles northeast of Berlin, as assistant in the surgical department under Dr Schneider. Although a friend and mentor, Schneider denied permission for Forssmann's plans to attempt the procedure on patients or on himself. Forssmann could not be deterred, however, and he decided to carry out the experiment upon himself. A wide-bore needle was inserted into a right cubital fossa vein, through which a ureteric catheter (4 French) was passed for 35 cm without difficulty. His colleague, who performed the operation, flinched and abandoned the procedure. One week later, Forssmann anaesthetised his own left cubital fossa, advanced the catheter into his right atrium and then climbed several flights

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of stairs to the X-ray department and documented his achievement. This account was published on 5 November 1929. The first and only clinical application in which he used his catheter was to administer glucose, epinephrine hydrochloride and strophanthin to a woman with terminal purulent peritonitis following perforation of the appendix. After a temporary improvement, the patient relapsed and died; at autopsy, the catheter was found to have passed through the right atrium and its tip was situated in the inferior vena cava.

Forssmann (1931) pointed out that such a catheter could be used for central venous blood sampling as well as for injections. He also realised that the technique he had pioneered provided many possibilities for future metabolic studies and investigations into cardiac function. Later he was the first to inject a radio-opaque substance directly into the right heart via both arm and thigh veins (on himself) using uroselectan. Thus, he demonstrated that a well-known experimental technique could be applied to the study and treatment of disease in humans.

His enthusiasm for this discovery did not extend to his contemporary German colleagues, and little interest was shown in his work. He spent 6 years as an army surgeon in Germany, Norway and Russia and returned weary and malnourished to civilian medical practice. He turned to urology before receiving his unexpected and belated academic reward.

A short hiatus in this field of clinical physiology occurred until the systemic physiological investigations of Cournand, Richards and others commenced in 1936. A new flexible radio-opaque catheter was designed to enable intravenous and intracardiac blood sampling to be performed together with pressure recordings in the right atrium and pulmonary artery. They performed studies in heart failure, valvular heart disease and shock, and stimulated many other workers in this field around the world. For those who may be particularly interested, a definitive account of this period has been provided by Cournand (1975).

The introduction of flexible polyethylene cannulas for intravenous feeding in children was introduced by Meyers (1945) and Zimmerman (1945), and this innovation from the plastics industry heralded the beginning of an era in intravenous therapy and diagnostic intervention. Surgeons adapted the tubing with ingenuity; for example, the palliative treatment of obstructive hydrocephalus became a reality in May 1949, when Nulsen and Spitz (1952) established a valved shunt between the right lateral ventricle and the right internal jugular vein. They recognised the failure of the intravascular prosthesis caused by thrombosis inside the shunt and the jugular vein. The techniques derived from this procedure are now applicable for the direct cannulation of the internal jugular vein in the most difficult cases requiring parenteral nutrition.

The mass production of cannulas and central catheters consisting of polyvinyl chloride was inevitably followed by numerous clinical case reports and series describing local and systemic complications (Morris 1955, Moncrief 1958, Crane 1960, Doering *et al.* 1967, Neuhof and Seley 1974). Indar (1959) pointed out the problem of thrombosis which occurred when polyethylene catheters were used in the deep veins. Industry thus continued to research for improved inert materials for use as intravascular protheses. Tetrafluoroethylene (TFE) and fluoroethylenepolypropylene (FEP) have been used and the incidence of thrombosis reduced as a result.

Quinton *et al.* (1960) jointly developed a Teflon and subsequently a Silastic arteriovenous shunt for use in haemodialysis. This advance has proved to be of tremendous

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significance in the achievement of safe chronic venous access. A Silastic intravenous catheter was introduced (Stewart and Sanislow 1961) at Ann Arbor Hospital, Michigan. The tubing they used was extruded and cured at 480°F for 16 hours, the cannula being connected to the intravenous administration set by a 20-gauge needle after the point had been removed by grinding. Herein lies a problem of the inertness of silicone; namely, it is extremely difficult to bond the catheter to the hub securely. Mechanical catheter-related problems have now assumed importance in the care of patients receiving prolonged intravenous therapy (Fleming *et al.* 1980). Design alterations are still needed in order to make further improvements in this aspect of patient care.

Current central venous access devices are fabricated from silicone, polyurethane or polyamide and research continues to provide reduced thrombogenicity of the intravascular portion of the device and at the same time provide a strengthened durability of the extravascular and extracorporeal segment of the infusion system.

Venous access and the development of parenteral nutrition

During the past 30 years, there has been a substantial increase in the number of patients who have received parenteral nutritional support in hospital. The terminology emerging from the scientific literature includes such new abbreviations as IVH (intravenous hyperalimentation) and TPN (total parenteral nutrition). Following the refinement of long-life silicone tunnelled catheters introduced by Scribner *et al.* (1970) and Broviac *et al.* (1973), home parenteral nutrition (HPN) has emerged as a reality for a few carefully selected patients. The infusion of energy substrates and nitrogen has been established as an integral feature of the supportive medical care of patients during severe medical or surgical illness.

The progress from the experiments by Sir Christopher Wren in 1656, when he infused wine, ale and opium into dogs, follows a fascinating path. John Hunter made some poignant observations throughout his surgical career; in his *Treatise on the Blood, Inflammation and Gun-Shot Wounds* published in 1794, Hunter discussed the aspect of wound healing which he termed ‘union by the first intention’. The words he used then and which have often been quoted since are:

> *It will be proper to observe here that there is a circumstance attending accidental injury which does not belong to the disease, viz. that the injury done, has in all cases a tendency to produce both the disposition and means of cure.* (Hunter 1794)

Central venous catheters have played a vital role in current medical and surgical practice enabling clinicians to monitor, augment and support the efforts of the body to stabilise the circulation during (or following) major surgery and provide nutritional supplements in order to fire the ‘disposition and means of cure’.

Following its isolation and purification, glucose was used intravenously in animals by Bernard (1843). Latta (1831) administered an infusion of water and saline to an elderly victim of cholera. Six pints were given intravenously in 6 minutes and the first complication of intravenous therapy recorded – circulatory overload. The populations of Asia, Europe and North America were intermittently attacked by epidemics of cholera

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and typhoid throughout the eighteenth century, and some of the earliest crude attempts at providing fluids and nutrition were made on the unfortunate victims of this disease.

In 1859, Hodder (1873) of Toronto suggested to his friend James Bovell that it would be 'proper and a probable success' to transfuse blood into cholera victims. Bovell pointed out that the supply would quickly run out in an epidemic as few people would be willing to part with their blood, and they could not be sure the blood itself would not be diseased. This is the first record of infusion contamination being contemplated as a hazard. Hodder felt that the nearest available analogue of blood in abundant supply was milk, and he knew that it had been given intravenously to animals by Donné without a fatal result. Hodder and Bovell bided their time, and in 1873, the city fathers of Toronto were just as unprepared for cholera as in 1859. An old shed in the hospital grounds was made ready and the first cholera victim brought in a state of circulatory collapse. Four other medical officers were consulted and agreed about the diagnosis and hopeless prognosis. On announcing his planned experiment, Hodder was told he would kill the patient. All but one of the medical officers refused to stay and observe the proceedings. A cow was brought to the shed, milked into a bowl, the milk was filtered through a gauze and 14 ounces injected through a tube inserted in a cut-down venesection from a warmed syringe. The effect was 'magical' and the patient recovered his pulse and survived. Two other patients had this form of treatment, rallied and died during Hodder's absence from the shed. Hodder and Bovell were the first to realise that the cost of the nutritional fluids and apparatus could be a limiting factor in the provision of their treatment. They applied to the corporation for a cow and a few items 'indispensably necessary for the comfort and well being of patients'; these were refused and they thereupon sent in their resignation!

Malcolm (1893) published a classic description of *The Physiology of Death from Traumatic Fever* and noted that shock was simply one of the phenomena caused by injury, whether surgical or otherwise, rather than a complication. His work stimulated the study of metabolic processes in shock. The value of glucose infusions for patients was not accepted immediately. The work of Pasteur and Joubert (1877) had provided the impetus to produce sterile solutions for animal and clinical use. Sugar was first infused in humans by Briedl and Kraus (1971) in 1896, and Kausch (1911) first infused glucose for postoperative nutritional purposes in 1911.

The concept of providing intravenous nutrition was furthered when, in 1913, Henriques and Andersen (1961) injected protein hydrolysate, glucose and salt solution into goats for 16 days. Murlin and Ritchie (1916) infused fat experimentally for the first time in 1916, and 4 years later, Yamakawa (1920) was the first to use an intravenous infusion of fat in humans. The significance of this early work was overlooked until 1937 when Elman and his colleagues performed their experiments. Several basic questions concerning the metabolic response to injury were being investigated by Sir David Cuthbertson during the 1930s. He made a teleological proposition (Cuthbertson 1929, 1930) that an injured animal in response to injury is faced with a diminished food supply, and he suggested that the rapid early catabolism of tissues could be associated with the first signs of regeneration of the injured part. Cuthbertson (1929–1931) went on to perform outstanding investigations into many aspects of the catabolic response to injury. Cuthbertson (1936) pointed out that a high-protein and high-calorie diet after fractures of the long bones was beneficial in attenuating the marked loss of body proteins. Cuthbertson (1942) introduced the terms 'ebb phase' and 'flow phase' for the initial depressed period of metabolism and the later period of increased metabolic rate after trauma.

Elman (1937) demonstrated the effectiveness of a 5% amino acid mixture derived from a sulphuric acid hydrolysate of casein to which tryptophan and cystine were added. In dogs depleted of their blood by acute haemorrhage, regeneration of the plasma proteins was evident after 6 hours in the group fed with 5% amino acid and 5% glucose, whilst the controls who were given 10% glucose showed no evidence of plasma protein repletion after 6 hours and very little after 24 hours. Elman and Weiner (1939) reported the first use of protein hydrolysate in humans. Positive nitrogen balance was maintained in postoperative patients and in patients with inoperable carcinoma by providing 20 g of casein hydrolysate, tryptophan supplement, glucose and saline. Shol and Blackfan (1940) described the first artificial amino acid mixture used intravenously in humans.

During World War II, the importance of this work was becoming apparent. It was recognised that intravenous therapy with protein hydrolysates and 5 or 10% glucose given through peripheral veins failed to provide sufficient non-protein calories to ensure that administered amino acids would be used for tissue protein synthesis and regeneration rather than for immediate energy purposes. The alternatives were to give large volumes of fluid or very concentrated solutions. Fat emulsions were a promising alterative source of energy. The observation that the body could tolerate the intravenous fat emulsion issuing from the thoracic duct provided the proof which stimulated Wretlind to search for a suitable alternative emulsion that could be manufactured. In the USA, an emulsion derived from cottonseed oil (Lipomul) was associated with toxic reactions, and all fat emulsions were removed from the market. Wretlind and his co-workers in Sweden embarked upon a long series of experiments using an animal test system to find a suitable emulsion. Hakasson (1968) finally developed a soybean oil and egg yolk phospholipid emulsion free of toxic reactions, and the experimental dogs survived the 28-day test period. A study performed by Hallberg *et al.* (1966) found that patients were able to tolerate this compound (Intralipid), and in 1965, an adult patient with Crohn's disease was kept in a good nutritional state for 5 months, fed intravenously with amino acids, glucose, fat, electrolytes and vitamins. In the UK, Rickham (1967) and his colleagues started to use intravenous fat emulsions together with amino acids and sugar solutions in paediatric surgical practice during the period 1962–1967 for children who had required extensive intestinal resection. Hadfield (1966) administered high-calorie intravenous feeding in surgical patients whilst he was at the Radcliffe Infirmary, Oxford. He used Intralipid in combination with casein hydrolysates and noted reductions in the postoperative weight loss of patients undergoing partial gastrectomy and also improvements in the serum protein levels of patients with ulcerative colitis and severe intestinal malabsorption.

At the same time as these advances were being made in Stockholm and the UK, the use of concentrated glucose as an alternative energy source was being investigated in the USA. Following careful fundamental research into the metabolic care of surgical patients, Francis Moore (1959) in Boston described the use of the superior vena cava for the infusion of concentrated glucose. He also stated that ‘patients on prolonged intravenous feeding rarely gain weight by tissue synthesis, yet it is conceivable that this might some day occur as intravenous hyperalimentation is perfected and concentrated’. Dudrick *et al.* (1966) reported that they could successfully perform total parenteral nutrition in beagle dogs and match orally fed controls in weight gain, development and growth. Dudrick *et al.* (1967, 1968) and Wilmore and Dudrick (1968) went on to report similar results in humans. They were able to achieve their remarkable results in free-moving beagle puppies by using fine catheters, which after insertion into the central veins were tunnelled subcutaneously for a distance to the back of the animal's neck. Such catheters were kept in place for periods of 72–256 days of intravenous hyperalimentation. The American investigators used concentrated glucose solutions in order to provide an adequate calorific intake, and for this to be accomplished without a high incidence of thrombosis or phlebitis, a central venous infusion system was developed. This would appear to be the first recognition of the beneficial effects of tunnelling catheters and coincided with the development of the Hickman and Broviac catheters on the West Coast of the USA.

The need to provide an adequate supply of protein, calories, vitamins and trace elements to patients undergoing major surgery, following severe trauma or recuperating from intercurrent disease is well recognised. Peaston (1968) summarised the situation succinctly by stating:

> *In recent years, materials have become available whereby intravenous nutrition can be adequately maintained. The therapeutic decision not to use them is a positive action to starve the patient, and must in itself be justified unless the complications from their use outweigh the advantages conferred.*

Johnston (1979) suggests that when nutritional support has to be provided by the intravenous route, as much as 1600 calories may be provided per day in an adult by peripheral venous infusion. This should be the route of choice in patients requiring short-term nutritional support. However, where prolonged therapy is required, the incidence of painful thrombophlebitis becomes unacceptable for most patients and central catheterisation must be employed. The biochemistry and methodology of providing supplementary or total parenteral nutrition has steadily progressed and several comprehensive reviews have been produced (Bernard 1971).

Venous access and chemotherapy

This has been referred to previously in the initial historical development of this technique. The origins of peripherally inserted central catheters (PICCs) obviously can be attributed to Werner Forssmann. The advent of effective anti-cancer treatment for a variety of tumours which required prolonged venous access and multiple, often daily peripheral blood sampling, led to the development and introduction in 1975, by Hickman *et al.* (1979), of the Hickman Silastic catheter, which possessed a 1.6-mm lumen and a Dacron cuff, for prolonged intravenous therapy in patients with leukaemia and allied disorders. This has proved to be an invaluable innovation for the comfort and care of patients with such severe disorders. It was shown that the incidence of septicaemia, in patients having both their blood samples removed and receiving their intravenous fluids, chemotherapy and haematological support by the solitary Hickman catheter, was less than in the control group of patients being managed with conventional peripheral intravenous therapy (Hickman *et al.* 1979). A similar experience was also reported from The Royal Marsden Hospital, London, by Thomas (1979), and Blacklock *et al.*

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(1980) and colleagues working in Auckland, New Zealand. The Broviac catheter was of similar design with a finer lumen for the infusion of parenteral nutrition. These catheter types have evolved into multi-lumen variants. Modifications have been made to the tip, e.g. the Groshong catheter, in an effort to prevent reflux of blood into the lumen of the catheter resulting in the formation of thrombus, or influx of air due to a negative venous pressure.

Routes of insertion

The percutaneous internal jugular approach was developed by Dr Ian English *et al.* in 1968 for central venous pressure monitoring and intra-operative and post-operative fluid infusion at The Brompton Hospital, London (English *et al.* 1969a, b). Branthwaite and Bradley (1968) reported the use of the Seldinger technique to introduce fine-bore cannulas fitted with thermistors via the internal jugular vein, whilst they investigated the measurement of cardiac output using the thermodilution principle at St Thomas Hospital, London. Other descriptions and variations of surgical technique were subsequently published (Boulanger *et al.* 1976, Prince *et al.* 1976, Rao *et al.* 1977, Coté *et al.* 1979).

Percutaneous infraclavicular subclavian vein catheterisation

The veins of the arm were used exclusively for central venous cannulation, when Aubaniac (1952) first introduced the concept of using the infraclavicular subclavian vein as a site for venepuncture. His technique was adopted by Keeri-Szanto (1956), Villafane (1953) and Lepp (1953). Initially, the technique was restricted to venepuncture for obtaining blood samples or giving injections, and central catheterisation via the subclavian vein was not performed. In 1954, Aubaniac performed angiocardiography using this approach. A further 8 years elapsed before Wilson *et al.* (1962) pioneered the introduction of flexible central catheters into the superior vena cava by this route. The technique was first described in the UK by Ashbaugh and Thompson (1963), while they were working in Edinburgh.

A supraclavicular approach to subclavian vein catheterisation

The introduction of cannulas into the subclavian vein via percutaneous techniques found favour by those clinicians who thought this might be a way of avoiding the complication of pneumothorax. Yoffa (1965) introduced the percutaneous supraclavicular approach to the subclavian vein for this reason. Argument continues as to whether the supraclavicular or the infraclavicular approach is safer.

Imaging

The development of techniques to carefully check the intravascular site of the catheter, e.g. X-ray imaging, are, of course, not new but were introduced by Forssmann at the very outset. It has also taken some time for the use of ultrasound to be adopted for safer placement of central venous catheters. The author and his colleagues (Peters *et al.* 1982) used this technique in the late 1970s at University College Hospital, London. The continuing search for safer techniques must be pursued in order to avoid unnecessary and often catastrophic complications.

Conclusion

This chapter, hopefully, will provide a historical foundation for this manual and will indicate the needs and opportunities for improvements in this field of clinical practice.

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