Electromagnetic Field Smart Splint for Bone Fixing and Rehabitation Using NiTi Shape Memory Alloy

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Abstract

Patients who suffer from broken bone could be prescribed splints to support their treatment procedures. The normal fabrication style of tailored splints is talent dependent long and also the splints themselves create varied issues with regards to the patient's response. Between many different special characteristics of Shape Memory Alloys (SMAs) that they have the power to come to an original form once heated. However, the general modification of associate degree existing part will powerfully be affected by the thermal and thermo-s mechanical properties. Therefore, shape memory alloys have been discovered numerous materials, which may typically be classified into Nobel-metal based mostly, Cu based, Fe based, NiTi alloy based system and metalloid shape memory alloys. Electrical stimulation has been applied to a number of different ways to influence tissue and bone healing. Most of the early works were carried out by orthopedic surgeons looking for new ways of enhancing fracture healing, especially those fractures that had developed into nonunion. Electrical energy can be supplied to a fracture by direct application of electrodes or inducing current by use of pulsed electromagnetic field or capacitive coupling. Many of these techniques have not been standardized.

Key Words: Splint, NiTi Alloys, Shape Memory Alloys, Electromagnetic Field, Bone Re-habitation, Fracturs.

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Introduction

The best ability to apply splints can be a technical talent simply perfect with supervising and an understanding of the basic principles, therefore, the initial process to splinting needs a radical assessment of the broken bone and extremity conditions for correct designing so, casting procedures involves the resulting application of a non-circumferential support control which gives the natural swelling that happens throughout the acute inflammatory section of an injury its complete time to rehabilitate[1].

in order to reduce many complications accrue while bone casting, many factors should be considered, like (Compartment syndrome, Ischemia, Joint stiffness, Pressure sores, and skin breakdown, medical specialty injury, Heat injury, Infection, Dermatitis), therefore, When considering whether or not to use a splint the doctor should estimate the stage and severity of the injury, the potential for instability, the danger of complications, and also the patient's main necessities [2].

In the most conditions, the processes of tissue healing can happen in a quite controlled and fully suitable method [2,3].

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However, there are too many conditions where the speed and efficiency of the process can result on the success of any medical and surgical conditions, if it healed of an ulcer of the venous or, the surgical wounds healing, or bone fractures fixing, where in fracture processes, a patient cannot do his full normal functionality until the fracture has consolidated, and 90% of pain and numbness or muscles malfunctioning, though the full healing procedures may hold on for too many months If this process fails, then there may be some delayed fixing between the fractured bones, where the final healing processes take longer than planned, where bone fixing and healing never occurs [3].
main principles of orthopedics are into return and maintain bone morphology & statement a stage duty after the trauma to natural bone healing occurs [1]. This procedure can be done by casting, dragging; Surgical interfering. using the metallic fixation device, or by employ the properties of electromagnetic shock. In many cases, traumatically gained fractures will be healed, but for patients who have difficult or multiple fractures, there are many possible causes where the mechanism for all cases is poor because of blood outfit to the fracture fragments[3].

General background

The definition from the shape memory alloys (SMAs) can be used for a set of materials that have the power to come to some antecedently outlined form or size, once it exposed to appropriate thermal proceeding throughout the production of the designed material[4].
HODGSON et al.[4] introduced a definition of an (shape memory alloy): is that produced by a thermos elastic solid solution; the alloy goes through a martensitic conversion of a sort that enables the alloy to be poor-shapen through a multiparous mechanism less than the transformation (temperature) then The (deformation) shape is then invert once the jointed structure return to heating upon the original form.
The first registed observation of the form memory transformation was done by the Yangtze and browse (1951) in 1932[5]. They noted the alteration in the transformation in AuCd by the metallographic monitoring and electrical resistance changes & in 1951 the form memory influence was determined in an extremely bent bar of AuCd [4,5].
During 1956, Noguchi achieved main experiments that showed some increase in bone growth when using immediate electrical current[6]. Following by vivo work was done by Bassett et al, exersing a dog's femora and a 1.4 Volts mercury cell battery. probably, the most surprising outcome was the almost complete occupancy of the medullary cavity by the frish bone growth around the cathode, where the flowing current was about 100 μA[7].
Friedenberg and Kohanim continued to repeat more studies similar to Bassett et al work, by implanting live electrodes into the animal's tibia. With exposition times more than 20 days and the electric current flow into was near to 5 μA the experiments showed that there was very thin bone formation around the cathode, but the best results were bone capacity around the anode [8].
The next evolution studies were depending on the wide knowing of the bone physiological-generation of new tissue was accomplished with the help of a direct charge that varied with the load. These developments goals were concentrated on the generating of electric fields applied to the fracture sites [7]. If it is reasonable to increase the physiological electric amount at the fracture site, it is potential to show the bone healing process by turning the natural response to the injury [7,8].

Generating an Electrical field

Practically, There are 3 ways to control electric fields effects on the fracture site[8,9]. which are the application of direct current through implanted electrodes, and generate passing alternating micro-currents passing through the fracture site non-invasively by capacity induction, and generate a transient micro-currents by electromagnetic induction, as shown in Fig.1.[9]
The direct implementation procedure of an electric current is safest& measurable way of applying the electrical energy with current flow through the bone transmitted ionically, one electrode will be just like the cathode and the other is the anode actually, a large quantity of the power will be submitted in that mode also it is the only limit of safety from electric shocks[9].

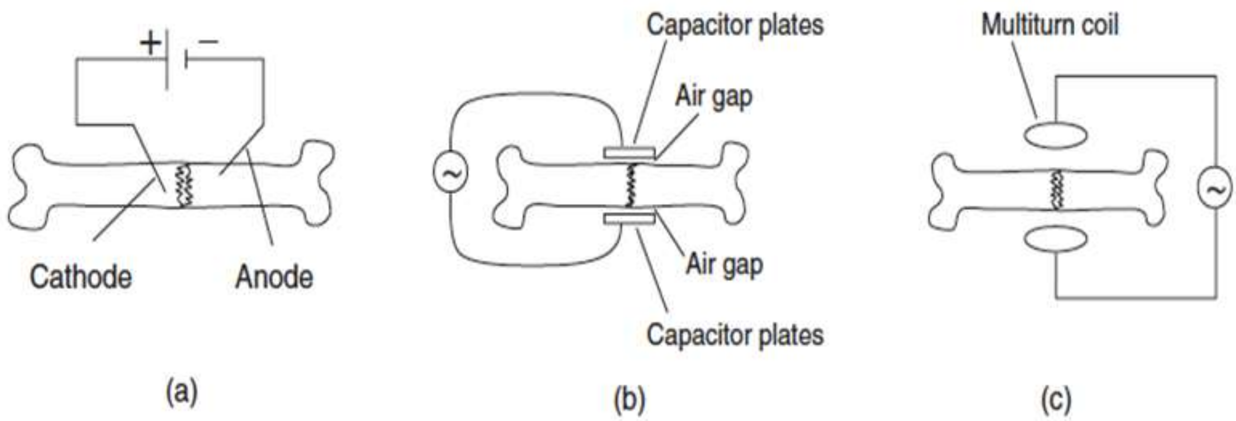

Fig. 1. An electric field interacting with a fractured bone. (a). In (b) show the direct current stimulation method, 2 identical electrically conducting parallel plates are used as shown and connected to an alternating current source where the bone is a dielectric material. (c) This figure shows a method of application of paired coils to generate an inductively coupled electromagnetic field in a fractured bone. The coils are identical and separated by a distance equivalent to the diameter of an individual coil [10].

The alternative current flowing directly to a coil of wire or solenoid will provide a time-changing magnetic field in the axis of the coil and at the itself time-varying electric field along the itself axis and it is vertical to the magnetic field, therefore this is very common to notice that, the opposite side to direct application of the electrodes, there is no real current flow in conductors within the coil and there should be a very fast adjustments in the magnetic fields to generate the significant electric field part[10]. There is a practical limitation to achieve this instant rate of change in the magnetic field which is very important to drive the electric current into that coil very quickly as the pulses then, this becomes difficulty due to self-inductance where the magnetic field produced in that coil, will encourage the electric current to flow in the direction opposite side to that was supplied, which will present to dampen the increased in current passing through that coil, therefore to the electric field magnitude which can be transiently created [10].

Optimization intensity of the current

The best current needed to create a transformation temperature is very necessary to control full advantage. It can be done by examining the shape memory alloy sample at two various upper levels of currents (750 mA and 1100 mA)[11], submitted to two various loads (8.5 and 26.80 MPa)[11]. These enhancements processes are also useful, to get the range of the threshold current up to which shape memory alloy wire becomes overheated[10,11]. Moreover, it supplies the quantity of threshold current underneath which it less performance[9]. Fig.2a shows the isolation curves of the shape memory alloy wire at 1100 mA and 750 mA of currents at stresses of 8.5 and 26.8 MPa. The corrseponding pulses of the current are shown in Fig. 2b[11].Using pulse heating method and the cooling means are various because pulse time is proporsed to be fixed in this article. The isolation curves of (1100 mA) current have an initial start with very big rate of displacement, this rate goes down at the higher current range because of the "recovery of maximum strain". In the same time, for the displacement curve of 750 mA, displacement in the wire begins later with little minimum amounts but appears to be bigger linear domain if contrast to 1100 mA displacement curve[10,11]. The best current power is acquired from the identical current pulses by drawing the vertical form of the displacement curves. The meeting points of the cross-over on the current pulses Fig. 2b acts as the best conversion of the current[11].

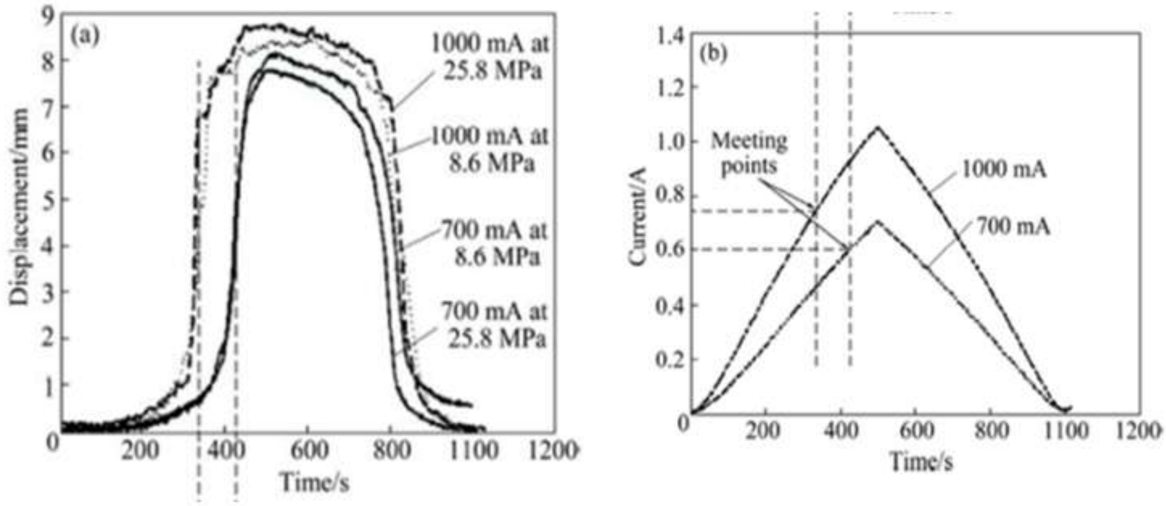

Fig. 2. Shape memory alloy wire displacement by current pulse of 1100 mAand 750 mA

Heat transfer pattern of the transformation temperature

There are many difficulties of measuring the wire temperature due to its less size of dimensions and surrounding situation therefore, the heat transfer analysis of the wire was done by "mass parameter convective heat transfer equation"[10]. The convection of heat transfer model equation define the average value of the heating and cooling according to the passing electrical current through the wire[10].

Simple one dimensional heat transfer term that characterizes the shape memory alloy wire for resistive heating and the cooling under surrounding air load is [12] :

$$mc_p \frac{dT(t)}{dt} = vI - h_cA_c[T(t) - T_a] \text{.................(1)}$$

where (m=ρπd2l/4) is the wire's mass; (ρ,l, and d) defined as the density, length and the diameter of wire; (cp) is the given heat capacity; (hc) defined as heat convection coefficient for surrounding cooling status; (Ta) is the surrounding temperature; (I) is the current flow through the wire; (v) is the potential variation across the wire; (Ac=ρdl) represents the convective surface-area of the wire[12].Heat transfer term assume that the influence is one-dimensional and the lamp which statified to wire is constant, the radiation actions can be unsavory matched with conduction mode of heat transfer, volume and area changes are minor or negligible, also, (T_a& h_c) both are constant. The temperature range of the wire is spatially regular and the temperature of the phase transformation are constants as well. The impact of heat radiation can be neglected as the active temperature is less than 200C°. (Eq. 2) is used to have the greater temperature T of the shape memory alloy wire[12].

$$T - T_a = (T_0 - t_a)e^{-t/\tau} + \frac{vI}{h_cA_c}(1 - e^{-t/\tau}) \text{.................(2)}$$

where T_0 is primary temperature of the wire, τ (time constant) =(mc_p / (h_cA_c)). The variation of temperature through electrical power through the heating and cooling cycle is gained by taking in mind the first temperature which is equal to the surrounding temperature[12]. so, Eq. (2) becomes

$$T = \frac{vI}{h_cA_c}(1 - e^{-t/\tau}) + T_a \text{..............(3)}$$

The wire temperature can be indirectly controlled by changing the intensity of the current passing over wire. The relative model variation begins at the wire while the temperature passes A_s "austenite start temperature" and ends at A_f "austenite finish temperature". Therefore to keep the wire at the "austenitic phase", the temperature must stay more than Af by putting the best power[11,12].

Shape memory alloy wire temperature is calculated from Eq. (3), and variables that are believed to use for computation measurements are current and voltage, wire diameter (381 μm), length (180 mm), Cp (322.384 J/(kg·°C)) and h_c (75 W/(m2·°C)) [12]. Figures (a), (b) show the shape memory alloy current and voltage signals. (c) and (d) show calculated temperature outline and thermal "hysteresis loop" of the area — temperature relationship[13].

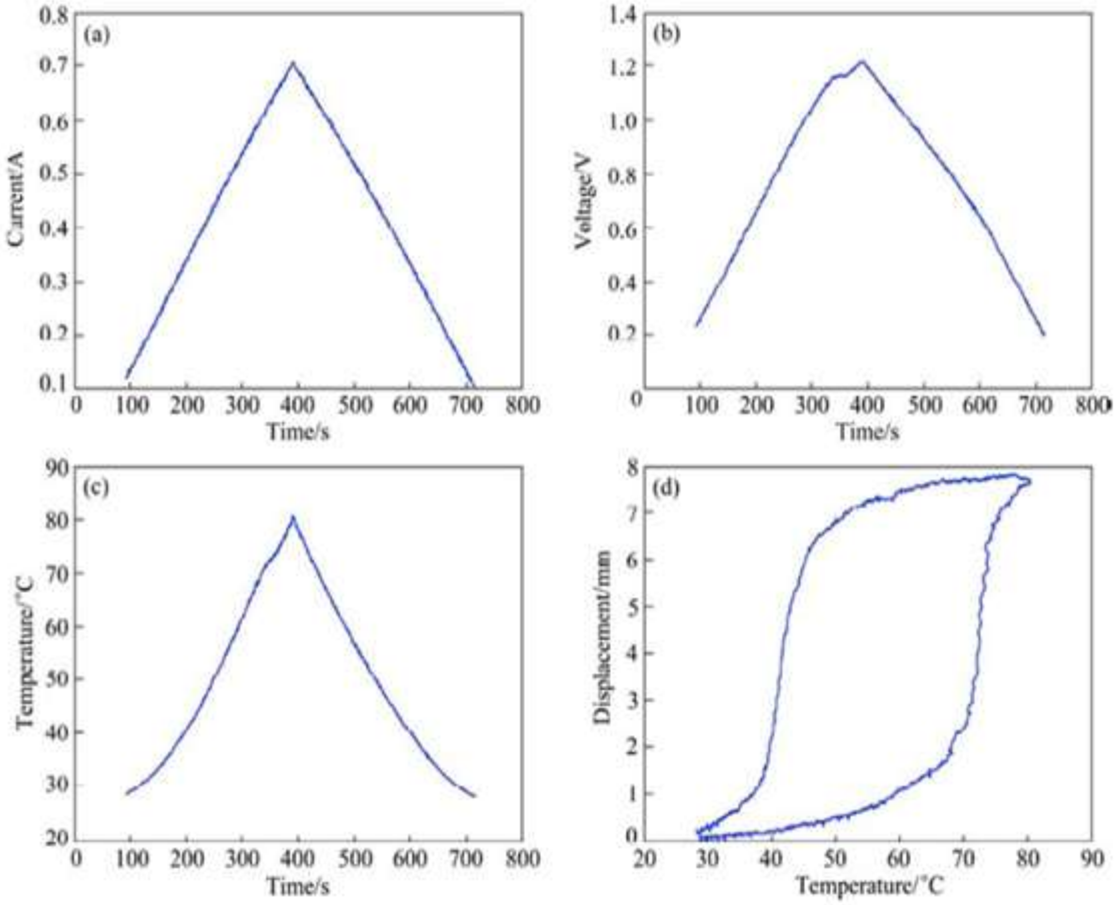

Fig. 3. The current (a) voltage (b) signals with time, computed temperature profile (c) hysteresis between displacement and temperature (d)[13].

Materials and Methods

Patients who were selected for this study have either ununited bone or delayed in reunion found in one of the long bones, also the bone union is considered to be late if the fractions were freely moving more than 3 months after injury, and if no notable steps towards union were noticed on radiographs before therapy starts[1].previous studies suggested that the effective healing processes of situations with non-union or delayed union demonstrate the efficiency of the new technique, no individuals monitoring groups were tested, but some judgments suggested by several supervisors and experimental results of a double-blind trial were reported by Barker et al.[2], These judgments were made on 9 patients with tibial non-unioned bone with 5 patients in the observation group[2,3].Barker et al used the pulse burst system of Bassett, but they had identical success averages (~70%) in both controlled and experimented groups. The study appears to conflicts the former reports on the efficiency of pulsed electromagnetic stimulation and offers the necessary needs for more investigation[6].

Shape Memory Alloy (SMA) transformation procedure can be done in an extremely solid-state, the ordinary term for the high-low temperature stage is solid solution and primary solid solution. The transformation is usually raised up as "martensitic transformation (M_T)", while heating the sample from the low-temperature martensitic dimension, the transformation solid solution into primary solid solution starts at the given temperature A_s (austenite starting point)[14], then the transformation is ended at the known temperature A_f (austenite finishing point)[14]. At this known temperature, the complete sample is made over again into the first solid solution phase, in the same way[15], while cooling processes from the high-temperature austenite dimension, phase transformation austenite into martensite begins at the fixed temperature M_s (martensite start) and finishes at M_f (martensite finish)[16].The table describes the transformation temperature for specific types of alloys[17].

Table 1. View of some most important SMAs

	Alloy	Composition	Transformation temp. range
1.	Ag – Cd	44/49 at %Cd	(-190C)–(50C)
2.	Au-Cd	46.5/50 at Cd%	(30C)- (100C)
3.	Cu-Al-Ni	14/14.5 wt%Al, 3/4.5 wt%Ni	(-140C)-(100C)
4.	Cu-Sn	Approx. 15 at% Sn	(-120C)- (30C)
5.	Cu-Zn	38.5/41.5 at% Zn	(-180C)-(10C)
6.	In-Ti	18/23 at %Ti	(60C)-(100C)
7.	Ni-Al	36/38 at %Al	(-180C)-(100C)
8.	Ni-Ti	49/51 at% Ni	(-50C)-(110C)
9.	Fe-Pt	Approx. 25 at %Pt	Approx.(-130C)
10.	Mn-Cu	5/35 at %Cu	(-250C)-(180C)
11.	Fe-Mn-Si	32 wt%cu, 6wt% Si	(-200C)-(150C)

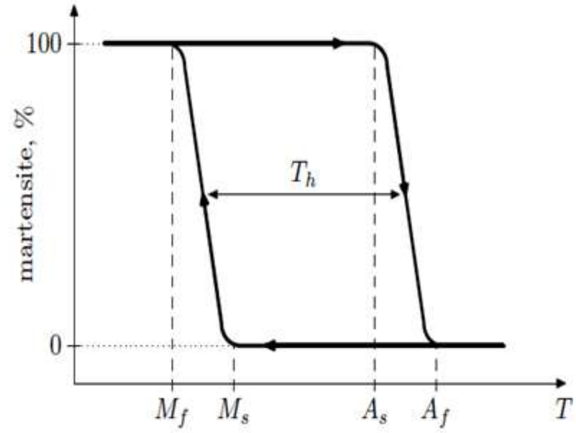

Fig.4. Temperature–transformation curve for a specimen subjected to one cooling– heating cycle.[17]

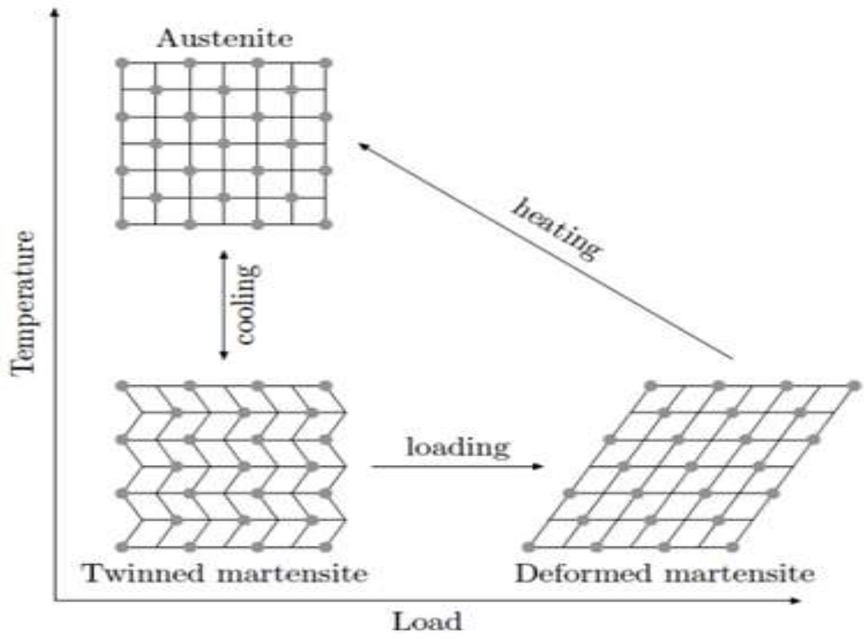

Fig.5. Four characteristic temperatures A_s, A_f, M_s and M_f of the phase transition process

The schematics illustrate the primary solid-state to primary solid-state transformation recovers the first form[18].The form of the sample in the martensitic section is weak-shapen material, once apply heat on it will Leeds to transform to the austenite section where the atoms will reposition into their original places, once the specimen is cooled it will stay in its original form[18].Martensitic transformations on NiTi alloys can be done in a single-step B2 to B19′ and vice-versa, depending on heating and cooling, the sample is being hardened and switched off by a single-step change, as in the differential scanning measuring (DSC) chart, because there is one single special peak on cooling from the B2-system (temperature changes any time the B2 section is stable) and one special peak on heating from the B19′ system[18,19,20].

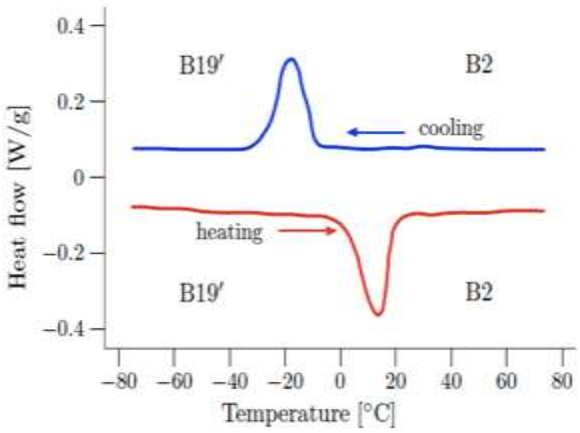

Fig.6. DSC chart for a single-step martensitic transformation in NiTi shape memory alloy

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The increasing R-phase makes a significantly less distortion and too minimal distress by the particles, so the existence of residues support the shape of R-phase who ends within the first transformation step B2 to R and simply, later at low temperature (strong undercooling) the 2nd transformation step is R to B19′ (2nd DSC peak) is specified[19,20].

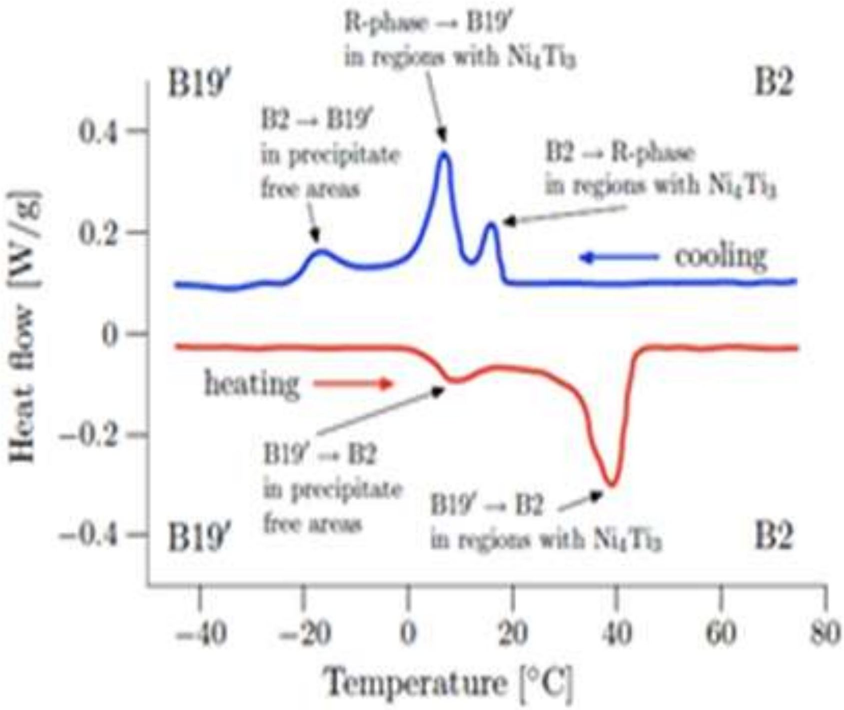


Fig.7. DSC chart used for multiple-step martensitic transformation in NiTi shape memory alloy with Ni_4Ti_3 precipitates.

Results

The new model of splints consists of a group of 3 different shape memory alloy's wires with different transformation temperature range between (10-50C), these wires redistributed as net wires, the first shape memory alloy wire will have its transformation shape at low temperature, the second wire will have the transformation temp. at normal range and the third wire will work when connected to an electrical field (700mA) which will produce an electromagnetic field for fast healing with the help of the electromagnetic properties as mentioned.

Discussion

The process of switching between different types of wires according to the required temperature will perform an additional process for its primary role in the upkeeping of broken bone, which is a process of a continuous massage of the tissues and muscles surrounding the fracture, which leads to a permanent activation and not to feel numbness or muscle stiffness during the incubation of the broken bone.

as a result of using the new splint, (the new splint was used on a broken arm) we noticed that the period of healing is less than the ordinary splint (less than 5 weeks for an adult), also, the patient was able to move his hand fluently and with less pain than before because of the use of electromagnetic field and the transformation between the three shape memory alloy wires as a procedure of healing process.

The new splints has many advantages according to the tests were done:

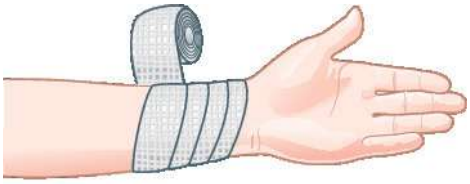
Easy to use; Better looking than the ordinary splint; Enable the patient to move more fluently; Small size (relating to storage and marketing); Suitable for many places according to the super elasticity characteristics. However, the new design has some disadvantages:

Rather expensive; Relatively heavy weight; Needs power supply for the heater.

The Electronic Splint Consists of Two Parts:

Part One:

- 3 sets of shape memory alloy wires separated by a thermal insulator putted on a pad with (20-30) cm long, and (5-10) cm width.
- the shape memory alloy wires have the effective shape as a (spiral shape)



Spiral Turns

- Image of the 3 shape memory alloy wires have these specifications:

Part two:

- A plastic cover for pad's protection and assisting, also it can be used as a housing for the electronic parts (power supply, charging system,..etc.)

Conflict of Interest Statement

Authors declare that there are no competing interest

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