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(54) **Interdigital webbed swimming glove**

(57) Surface enlargement of the swimmers hand using flexible material allows to influence position and size of the propelling surface due to the interposed digital rays, controlled by activity of the intrinsic and extrinsic hand muscles. Furthermore finger anatomy with articular connections between the separate parts provides for additional flexibility. Consequently changes of position size and shape are possible not only for the web as a unit, but also for the separate parts of the web in relation to each other. One of the key features of artificial webbed gloves (figure 10) for human swimming is the position of the web insertion at the digital rays. The optimum insertion point is located directly opposite to the insertion of the abductonal muscle force vector (figure 11,12,13). This position of web insertion leads to an enlarged hand surface, which is curved two-dimensionally and further tensioning of the flexible web can lead to palmar shifting of the insertion point with smoothening of the surface. These characteristics probably lead to lesser deviation from physiologic stroke pattern compared to paddles.

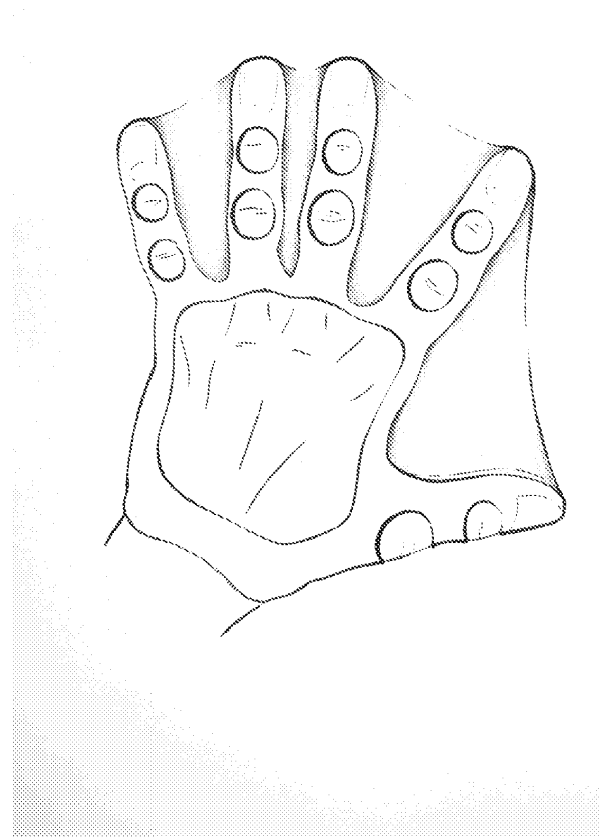


FIG 10

**EP 2 543 417 A1**

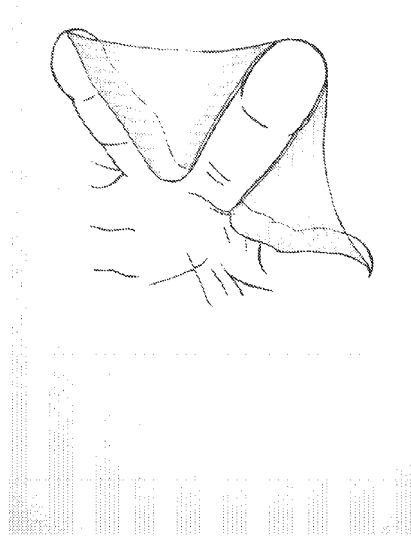


FIG 11

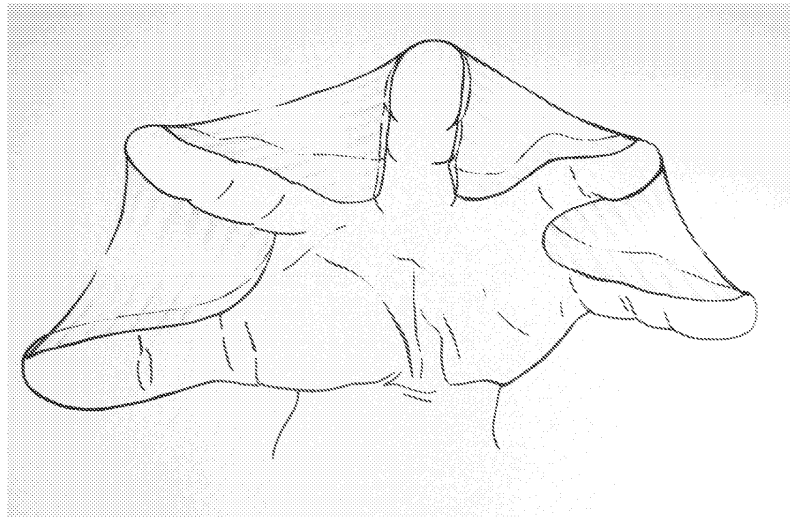


FIG 12

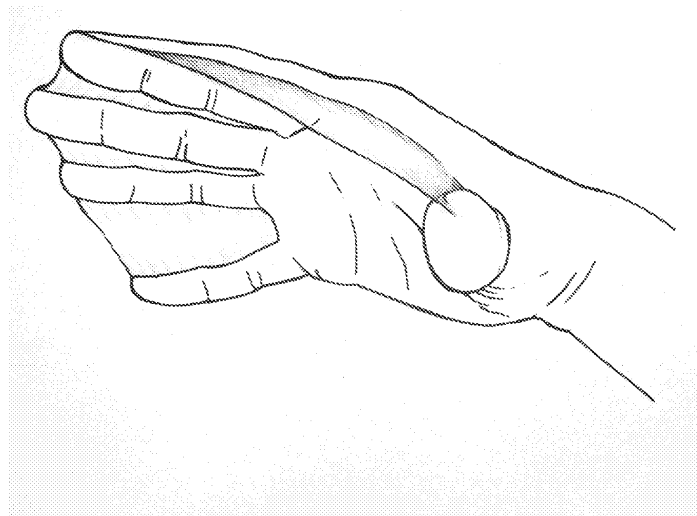


FIG 13

## Description

### Field of the invention

**[0001]** The invention concerns a device that supports and optimizes human swimming. The device is an interdigital webbed glove made from materials of different flexibilities combining the principle of flexible hand surface enlargement with functional and anatomical aspects adapted to the characteristics of aquatic locomotion in general and to human swimming kinetics.

### Background of the invention

#### Principles of aquatic locomotion

**[0002]** While terrestrial locomotion bases on frictional forces between solid ground and the moving organism, the major principle in aquatic locomotion is drag due to inertial forces (Hoar 1978). In most aquatic species, the principle of surface enlargement for thrust generation is realised with characteristic *webbed appendages*. Aquatic and semiaquatic animals move in water using different techniques depending on shape and function of body and appendages. The scientific classification of aquatic locomotion in animals was specified since Breder (1926) described various modes of swimming in fish. *Undulating* body movements enable fish, swimming in this mode, to generate five times higher propulsive drag than species with a similar *rigid* streamlined body. Many rigid-bodied animals, however, are propelled by *oscillating* appendages (Lighthill 1975).

#### Kinetics in human swimming

#### Contribution of arms and legs to propulsion

**[0003]** In freestyle, frontcrawl, backcrawl and breaststroke being the classic human swimming modes the main propulsive force is provided by the use of the upper extremity (Bucher 1975, Faulkner 1966, Hollander 1988). Kicking causes a considerable increase in the energy cost in swimming (Astrand 1978, Charbonnier 1975, Holmer 1974, Adrian 1966).

#### Stroke pattern in human swimming

**[0004]** Analysis of stroke patterns of hands in champion freestyle swimmers revealed, that instead of pushing water on a straight line backwards, the hand follows a *complex three-dimensional curvilinear path* (Brown and Councilman 1971).

**[0005]** In the opinion of Maglischo (2003), Newton's third law of motion, the *law of action-reaction*, is the principle that most likely explains human swimming propulsion. The lateral and vertical deviation from a straight backward oriented stroke leads to an increased distance and overall increased propulsive stroke. A stroke which

is directed straight backward would require a much greater muscular force to push against the water that has already been set in motion. In addition those deviations could partially be understood as counterbalancing actions by legs and arms to maintain a straight course and hence avoid loosening of body alignment. The attempt to bring the stroking hand under the midline of the body interferes with those counterbalancing actions. Sudden changes of the direction require, according to Newton's first law of motion (law of inertia), additional muscular effort to react. To overcome inertia less effort is required if changes of limb direction are completed gradually over a longer distance (Maglischo 2003).

#### 15 Paddle swimming

**[0006]** Comparison of swimming with flexible webbed hand gloves to paddle swimming is obvious.

**[0007]** Essential presumptions, evaluating characteristics of paddle swimming are

- that giving a small amount of water a large velocity change costs more kinetic energy than giving a large amount of water a small velocity change (Toussaint 1992) and
- that the waste of energy is larger using shorter strokes with high peak forces than when longer strokes with a more uniform force pattern are employed (deGroot 1988).

#### 30 Influence of hand paddles on stroke patterns and forces

**[0008]** Both *propelling efficiency*  $e_p$  and *stroke length* apparently are increased when paddles are worn reflected in higher mean swimming velocity (Toussaint 1989, 1991, Gourgoulis 2008, Payton 1995) despite the reduction in hand velocity.

**[0009]** The impact on relative duration of the separate phases has been analysed, leading to different results (Monteil and Rouard 1994, Payton and Lauder 1995, Sidney 2001, Gourgoulis 2008, Stoner and Luedtke 1979, Schleihau 1979, 1983).

**[0010]** It has to be considered, that with increasing velocity energy expenditure rate increases exponentially due to the exponential increase in drag (DiPrampiero 1974, Holmer 1992). However the hypothesis that elite swimmers have lower resistance at high swimming velocities than poorer ones exists (Bober and Czabanski 1975, Councilman 1968). Higher swimming velocity enables the swimmer to ride in a higher position as a passive effect due to an increasing mass of water being diverted underneath the body. This eliminates the need for swimming with head held high and back arched, what can increase total resistive drag by 20 to 35% (Clarys 1979).

**[0011]** *Lift* and drag forces are significantly greater with large paddles (Gourgoulis 2008) and proportional to the area and the square of the relative velocity of the hand (Berger 1995, Payton 1995, Sanders 1999).

**[0012]** Swimmers using hand paddles are less forced to emphasise the final propulsive backward push (Payton 1995), being a key feature of the front crawl stroke (Schleihauf 1983, Counsilman and Wasilak 1982). In that way arm coordination and motor patterns are modified while swimmers use paddles. However muscle patterns and intensities were found to be similar when swimming with and without hand paddles (Ikai 1964, Vaday and Nemesuri 1971, Monteil and Rouard 1992,1994) except with paddles which were cambered (Bollens 1986).

**[0013]** Increase of the effective force is not the result of a deviation from the direction of the generated force (Gourgoulis 2008).

#### Flexibility of the propelling surface

**[0014]** Aquatic and semiaquatic species are adapted to the demands of aquatic locomotion possessing characteristic morphological features. Body shape as well as structure of body appendages are essential determinants for swimming performance. Surface enlargement on one and flexibility of appendages on the other side are two main principles employed. Combination of both allows to optimize movement through water by the use of propulsive drag forces.

#### Artificial leg fins in human swimming

**[0015]** Comparing performance of different *artificial leg fin designs* McMurray (1977) concluded, that *greater surface area would allow for force to be directly applied to the water and that the more flexible the fin, the greater is the speed*. An increased flexibility of the material permits a small portion of water to slide off the fin blade, resulting in less effort while maintaining propulsion, McMurray stated. However the advantage of flexible fins probably bases on another effect described in the following. Fins of fish are flexible and equipped with a system of intrinsic contractile elements, which allows modification of positioning and shape of the fin during maneuvering (Flamang 2008). That enables fish to apply force against water in a more effective way, using (in relation to the desired maximum drag force) an optimum angle of attack. An artificial leg fin for human swimming can not be directly influenced by contractile elements of the swimmers body. Fin positioning is realised through muscular activity of the leg and depends on the range of motion mainly of the ankle and to a lesser extend the foot joints. Under those restrictions compared to natural fins, flexibility at least partially allows to optimize the fin's angle of attack, hence enabling the foot to strike more effectively. Furthermore flexibility allows to transform the stroke into undulatory patterns. Results of Pendergast (2003) are in accordance with those considerations.

#### Concept of flexible surface enlargement

**[0016]** Interdigital webs of aquatic and semiaquatic

species are more or less flexible. The hind feet of aquatic frog species can serve as a model for artificial surface enlargement of the hand in human swimming. Although, different from human swimming, thrust generation in frogs is realised by the use of the legs, the underlying principle for forward movement is the same, as described above. Flexible interdigital webs allow for optimal three-dimensional positioning and enlargement of the hand surface in adaption to the phases of the swimming cycle.

#### Functional anatomy of the human hand

**[0017]** The human hand is considered to be the momentary result of a phylogenetic process, changing pectoral fins of early fish species into a highly differentiated tool for various daily activities.

**[0018]** To estimate the potential of the hand for contribution to aquatic locomotion, differences and similarities to extremities of aquatic or semiaquatic species have to be evaluated. Longfingers and thumb are separately analysed for functional anatomy.

#### Longfingers

**[0019]** Each of the long fingers consist of three phalanges, connected to each other and to the metacarpal bones by joints which are similar in anatomy and function. While extension of these joints from a neutral position is limited by passive tightening of palmar joint structures, flexion has a much wider motion range. In the plane of the palm of the hand (spreading) motion of longfingers in relation to each other is possible due to the abduction range of motion of the *metacarpophalangeal joints* (MPJ). The excentric insertion of the collateral ligaments at the metacarpal head causes tightening, during joint flexion hence reducing the abduction motion range of the finger.

**[0020]** In contrast the *interphalangeal finger joints* (IPJ) are locked against abduction by (in the extended joint position) tightened collateral ligaments on each side.

**[0021]** Active chagement of the relative position of the separate hand parts is provided by two motor systems. The principal part of the muscles originating from various surfaces of the distal upper arm and the forearm forms the *extrinsic muscle system* for the hand. These muscle units provide for movement of the wrist, as well as for movement of the carpal, metacarpal and phalangeal hand parts in all of the three planes. The *intrinsic muscle system* consists of different groups of short hand muscles with origin and insertion within the hand itself. There are complex agonistic and antagonistic interactions between separate muscle units within a system (intrinsic or extrinsic) as well as between muscles of both systems.

**[0022]** An important motor function of the intrinsic system is active abduction (spreading) of the longfingers in relation to each other.

**[0023]** For the long fingers this function is realized

through the Musculi interossei, for the little finger in addition through parts of the hypothenar muscles (M. abductor digiti minimi, M. flexor digiti minimi brevis). The amount of active spreading force is intimately related to the cross sectional area of the intrinsic muscles involved. Spreading strength is larger for index and middle finger compared to ring and little finger (Chao 1989). Fingers of the relaxed hand are slightly flexed in MP and IP joints. Prerequisite for forceful spreading of the fingers is extension of the MP joints, which is an effect of the Extensor digitorum communis muscle.

#### Thumb

**[0024]** The thumb possesses special functional characteristics. It's articular connection to the carpus provides for a wider range of motion of the carpometacarpal joint. Consequently the metacarpal part of the thumb is much more mobile than the corresponding parts of the longfingers, which enables the thumb to take a position opposite to each of the remaining fingers. Spreading of the thumb mainly is a combination of *anteponition* and *extension*. This action involves various motor units of intrinsic and extrinsic muscles depending on the plane in which abduction is done. Due to position of the insertion point the *Musculus abductor pollicis longus* (APL) is a forceful *extensor*, most effective for spreading. It's strength exceeds those of the intrinsic *Musculus abductor pollicis brevis* by far. The insertion point of the APL tendon (fig. 1) at the base of the first metacarpal bone is located palmar-radial.

#### Human interdigital web

**[0025]** The anatomic base of human interdigital web between the long fingers is the *Ligamentum metacarpale transversum superficiale* (Ligamentum natatorium) LMTS. Grapow (1887) called it "swim ligament". Numerous anatomical studies identified this structure as a rather untypical ligament consisting of threedimensionally oriented collagenous fibres (Gonzales 2006).

Similar to the claw frogs interdigital web (see below), the insertion of the ligament's fibres are located considerably palmar to the metacarpal bone axis (fig. 2).

**[0026]** The interdigital web between thumb and index finger also is located palmar to both ray's transverse axis through the bone shafts. At the thumb side the web inserts at a point directly opposite to the APL insertion point at the metacarpal bone (fig. 3,4).

#### Macroscopic and microscopic anatomy of African claw frog's webbed feet

**[0027]** Webbed hind feet of various frog species can serve as a model to assess the structure of appendages specialized for aquatic locomotion.

**[0028]** Frogs generate propulsive forces by pushing against a mass of water (Gray 1968) using drag and additional lift forces during the kick and glide phase (Gal 1988, Alexander 2002, Nauwelaerts and Aerts 2003).

5 The kicking surface is enlarged by interdigital webs. Hind feet of the African claw frog *Xenopus laevis* are webbed distinctively. The osseo-cartilaginous phalanges are articular connected to each other and to the metatarsus. A complex system of intrinsic muscles exists.

10 **[0029]** Webbed feet of anurans mirror the functional morphology of fish fins. The principle of a flexible surface with interposed rays, controlled by the activity of intrinsic contractile elements is realised in both groups of swimmers.

15 Webb flexibility

**[0030]** The interdigital web consist of a double epithelium layer with interposed connective tissue (fig. 5). To the distal end of the web the connective tissue layer nearly disappears. In these regions the internal cell layers of the epithelium of the plantar and dorsal surfaces get in contact (fig. 6). The surface of the African claw frog's interdigital web is smooth.

20 **[0031]** Spanning of the interdigital web preceeding the leg's extension phase is a result of muscular activity mainly of parts of the intrinsic system. Abductional muscular activity leads to a spanned web, with a double curved shape (fig. 7,8). Curvature in one plane is caused by a consecutive flexion of the interphalangeal and the metatarsophalangeal joints. Another curvature results from different distances of each ray in relation to the plantar plane. The first curvature is an effect of active joint flexion mainly due to extrinsic muscular activity. The latter is the result of abductional forces of intrinsic muscles.

#### Insertion of the interdigital membrane

40 **[0032]** The insertion of the web on the digital ray in histological cuts (relaxed) is located plantar to the transverse axis of the osseous phalanx (fig. 9). Spanning of the web probably even leads to additional plantar displacement of this insertion. The effect is a smoothening as well as the already mentioned curving of the propelling surface. Both effects apparently serve to optimize interaction with the liquid environment during the attempt to generate propulsive forces.

#### 50 Summary of the invention

**[0033]** The invention is set forth and characterized in the main claim, while the dependent claims describe other characteristics of the invention.

55 **[0034]** Purpose of the invention is to support human swimming. Using the device enables swimmers of different levels to optimize swimming performance. The main principle employed is flexible hand surface enlargement

under functional and anatomical aspects adapted to the characteristics of aquatic locomotion in general and to human swimming kinetics.

**[0035]** Natural selection lead to optimal performance of human terrestrial locomotion purchased by disadvantages for thrust generation in water. Undulating and oscillating locomotion requires specialized webbed appendages. Lacking those morphological characteristics human need to employ differing principles for propulsion in water. The main propulsive force in classic human swimming independent of swimming mode is delivered by the upper extremity and according to todays knowledge mainly bases on propulsive drag.

**[0036]** However, in opposition to the common use of leg fins in various modes of swimming and by swimmers of different performance levels, hand paddles available for human swimming are almost exclusively used by more or less high skilled swimmers during training.

**[0037]** The advantage of larger hand and arm surface for swimming performance has been proved comparing hands of swimmers with different performance levels (Toussaint 1991). Those findings confirm conclusions, that the mean propulsive force in human swimming is caused by propulsive drag. An artificial enlarged hand surface in freestyle correlates with higher propelling efficiency  $e_p$  and stroke length as well as higher mean swimming velocity (Toussiant 1989, 1991 Gourgoulis 2008, Payton and Lauder 1995). Swimming at higher velocities reduces resistance to water as an effect of higher body position (Bober and Czabanski 1975, Counsilman 1968, Clarys 1979). Flexibility of leg fins enables swimmers to generate propulsion due to undulating fin movements, which is a common mode of aquatic locomotion.

**[0038]** Hand paddles currently used for swimming at different levels contribute to swimming performance by an artificial enlargement of the hand surface. Those paddles are in general rigid. Surface enlargement of the hand using elastic material could improve swimming performance much more effectively.

**[0039]** Characteristics of the invention will be clear from the following description of a preferential form of embodiment, given as a non-restrictive example, with reference to the attached drawings wherein:

Fig. 10 shows the dorsal aspect of a flexible webbed glove with spreading of the finger rays in a midposition;

Fig. 11,12 shows a palmar view of a hand with tensioned interdigital web due to fully spreaded finger rays;

Fig. 13 shows the lateral (radial) view of the interdigital space between thumb and index finger.

**[0040]** Elastic membranes span over the four interdigital spaces from base to the tip of each finger (fig. 10). Those membranes are attached to the fingers by the gloves finger sheaths and are retracted in absence of muscular spreading forces. The elasticity of the sheaths

should be lower than for the web to maintain stability and the insertion point of the web in relation to the finger during spreading.

**[0041]** In contrast to paddles as well as to artificial leg fins, webbed gloves allow to influence position and size of the propelling surface due to the interposed digital rays, which can be controlled by intrinsic muscular activity. Abductional finger movement spans the interdigital membranes (fig. 11,12,13). The range of finger abduction leads to a graduated surface enlargement and tensioning of the membranes. The differentiated motor function of the human hand with articular connections between the separate finger parts provides for a three dimensional positioning of the interdigital web from the finger base nearly to the tips. Consequently changes of position, size and shape are possible not only for the web as a unit, but also for the separate parts of the web in relation to each other. In the area of finger joints the dorsal finger sheaths possess perforations in order to allow full range of joint motion also when a less flexible sheath material is used (fig 10).

**[0042]** The possibility of the more or less complete retraction of the artificial part of the hand surface due to passive forces allows to reduce resistive forces produced by the hand, which is espeacially important in the phase before the catch starts (in freestyle). Near the end of the stroke (on average at 80% of the total stroke time) maximum enlargement of the surface can be attained by active spanning of the web.

**[0043]** One of the key features of artificial interdigital webs for human swimming is the position of the web insertion at the digital rays (fig. 11,12,13). The optimum insertion point is located directly opposite to the insertion of the abductional muscle force vector. This position of web insertion leads (due to abductional activity) to an enlarged hand surface, which is curved two-dimensionally, similar to the spanned frog's web. Another advantage from the use of flexible material is, that further tensioning of the surface can lead to palmar shifting of the insertion point with smoothening of the surface.

**[0044]** These properties of the device are important prerequisites to adapt surface and tension to the different phases of the stroke:

In contrast to hand paddles flexible surfaces enable the swimmer to realise subtle changements of parameters to maintain optimum body position. In addition, the deviation from the natural path of hands and arms during the stroke should be reduced to a minimum.

**[0045]** On the other hand, the effect on energy expenditure, lift and drag forces, on the propelling efficiency and on the hand velocity would probably be the same, using flexible artificial webbed hand surfaces in relation to paddles.

**[0046]** Some additional potential advantages of flexible swimming gloves should be mentioned. Flexible hand

gloves In contrast to paddles enable swimmers to perform grab (Hanauer 1967) as well as pike starts, what requires to use hands for holding onto the block for pulling against the starting platform. For turns the required hand position can be maintained easier using flexible hand gloves.

**[0047]** The shifting of relative contribution to thrust generation from feet to arms (using artificial hand surface enlargement) may be helpful for swimmers, which are disabled because of loss of motor function of the lower extremity (people with paraplegia, stroke patients). The effect on energy expenditure was discussed above. During learning to swim, children as well as adults should advance easier using webbed gloves especially during the step from swimming with to swimming without buoyancy providing devices.

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## Claims

1. Webbed glove used for human swimming, consisting of the finger sheaths and interdigital webs between all five finger rays, providing flexible hand surface enlargement, allowing passive retraction after active

spreading due o muscular activity, allowing variation of positioning, size and shape of the propelling surface.

2. Webbed glove as in claim 1. **characterized in that** said finger sheaths are made of material of lower flexibility/elasticity in order to maintain stability and stabilize insertion point of the interdigital membrane on one hand but allows for movement of the finger joints nontheless.
 

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3. Webbed glove as in claim 1. **characterized in that** said finger sheaths possess perforations in the dorsal area of the finger joints to allow full range of joint motion.
 

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4. Webbed glove as in claim 1. **characterized in that** said interdigital webs span between the five finger rays from base to tip of the finger.
 

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5. Webbed glove as in claim 1. **characterized in that** said interdigital webs insert at the finger sheaths (from thumb to little finger) at a functional and anatomical insertion point, which is located near the plane of the palm of the hand where rudimental human interdigital web is located.
 

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6. Webbed glove as in claim 1. **characterized in that** said interdigital web between thumb and index finger inserts on the thumb side at the point opposite to the insertion point of the most forcefull spreading muscle of the thumb.
 

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7. Webbed glove as in claim 1. **characterized in that** said interdigital web is made of material of high elasticity to allow optimal surface enlargement of the swimmers hand.
 

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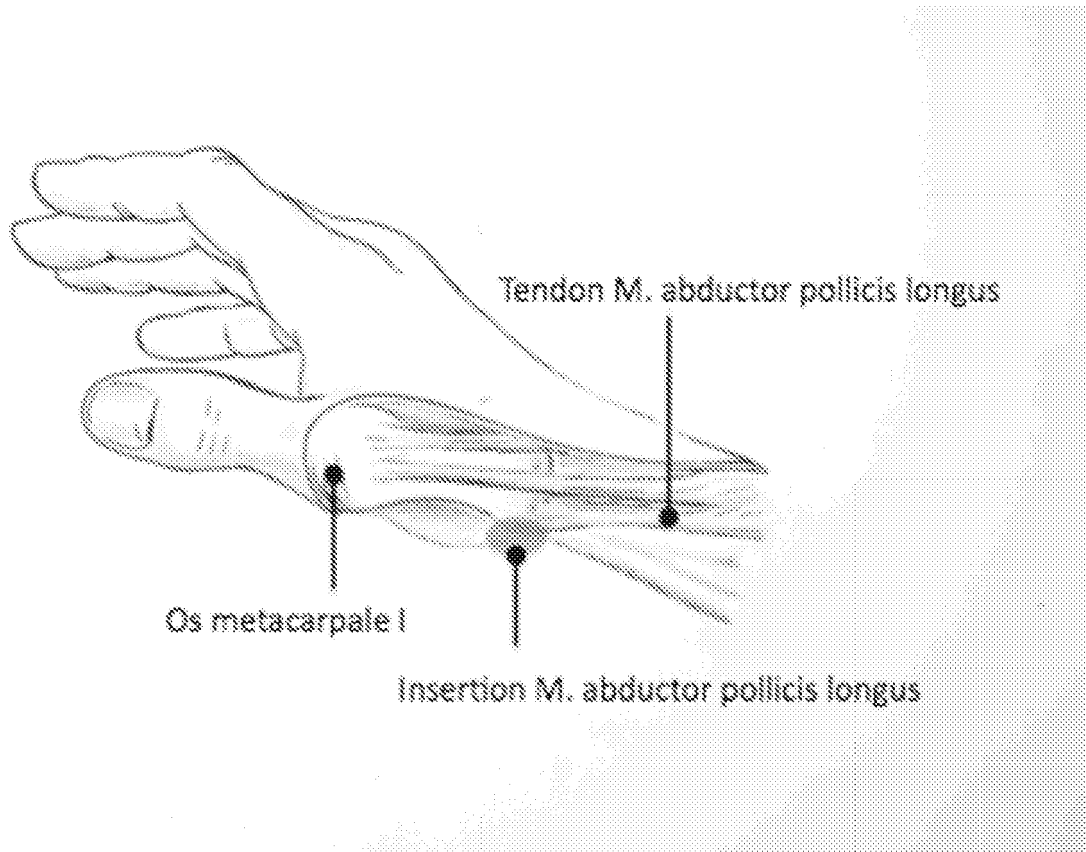
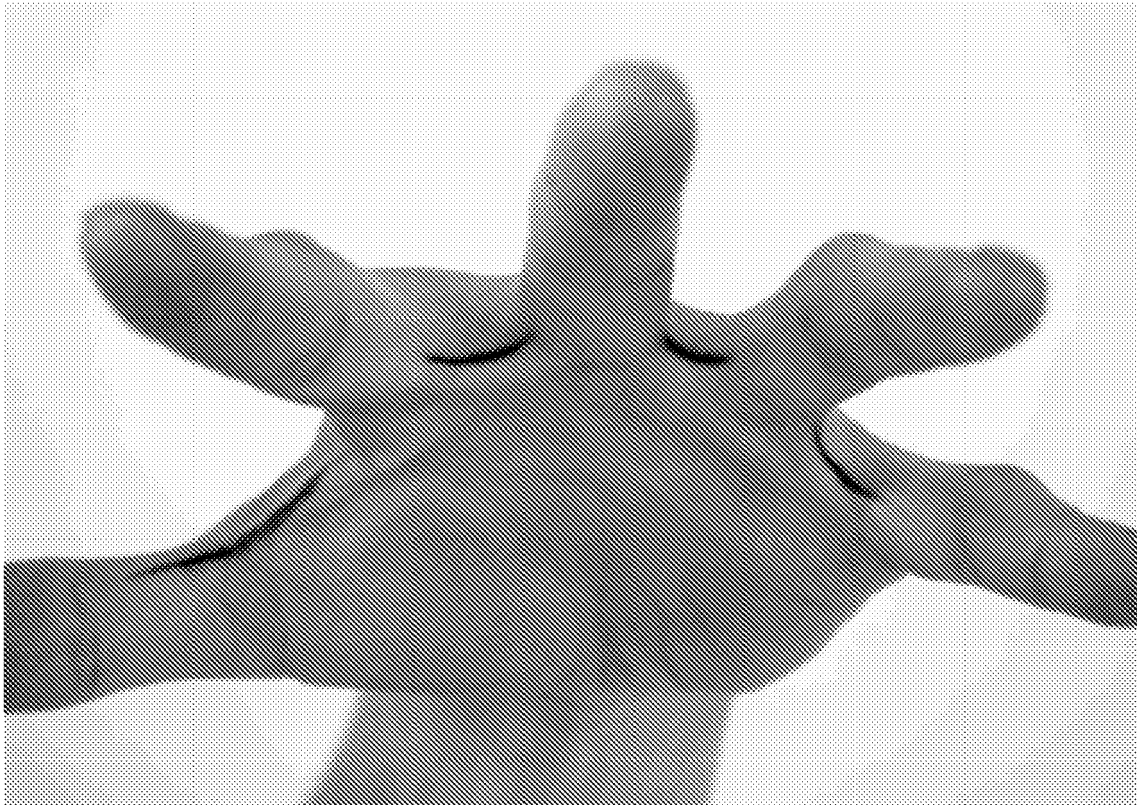
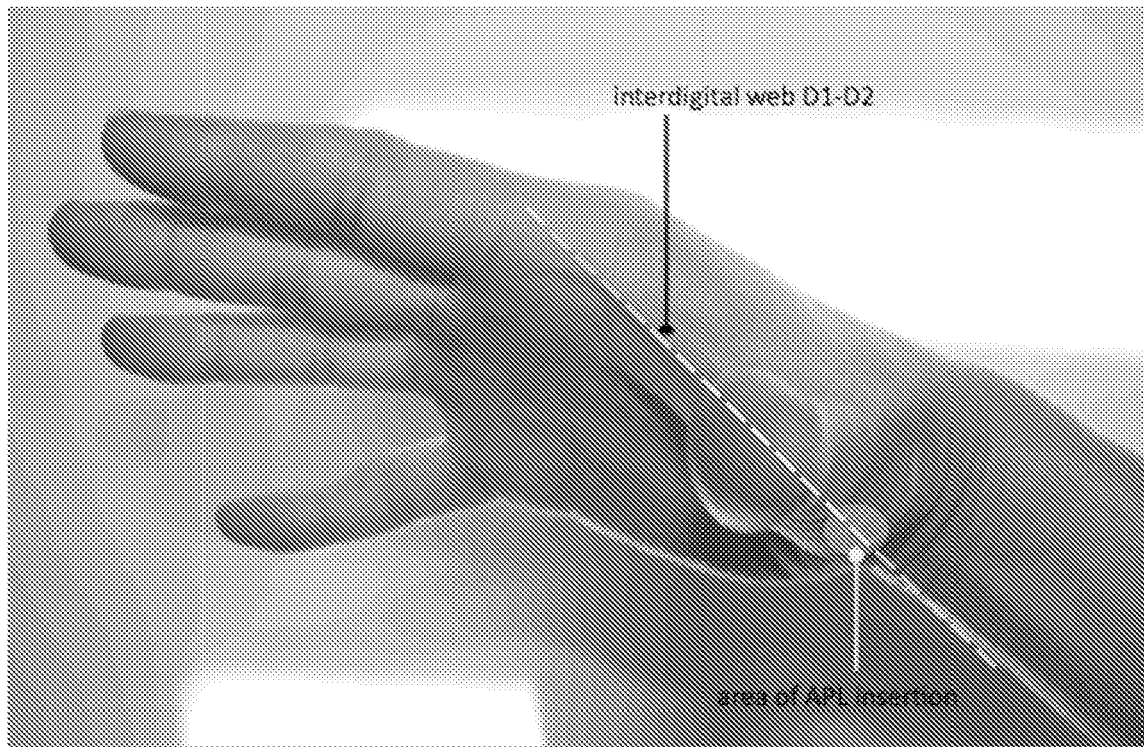


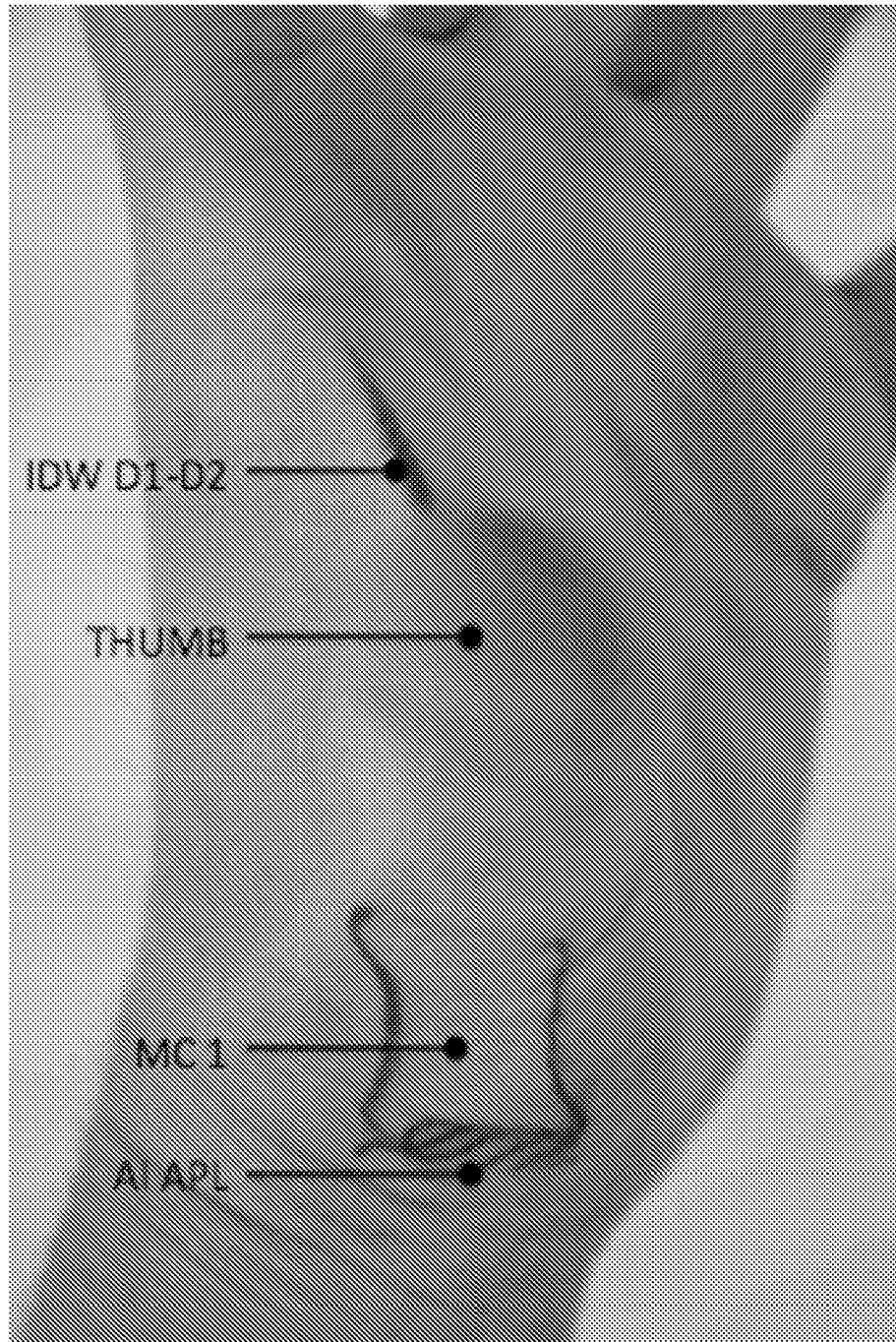
FIG 1



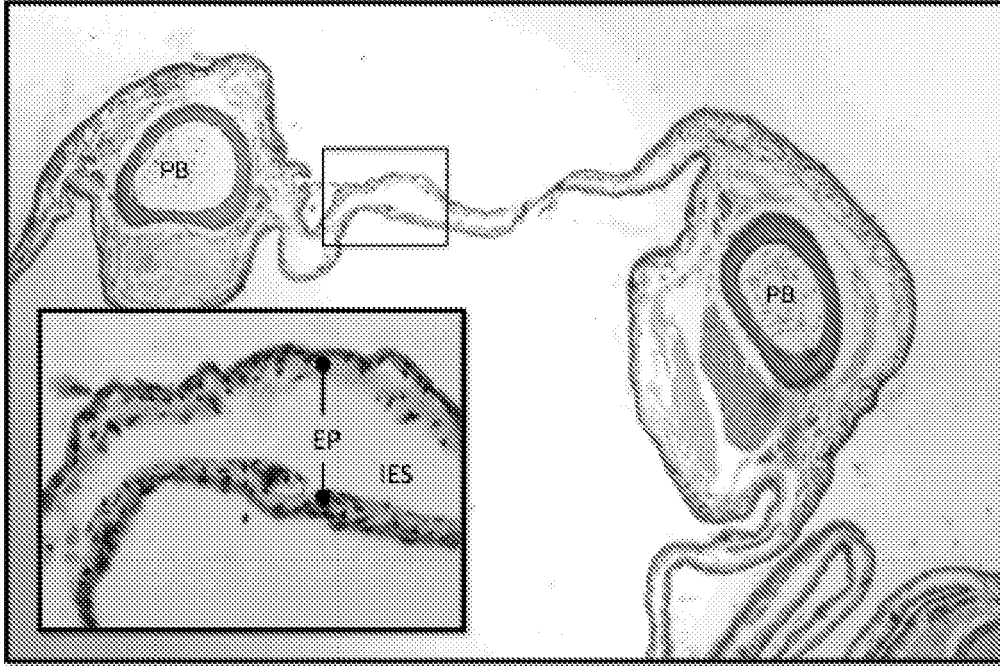
**FIG 2:**  
Position of rudimental human interdigital web



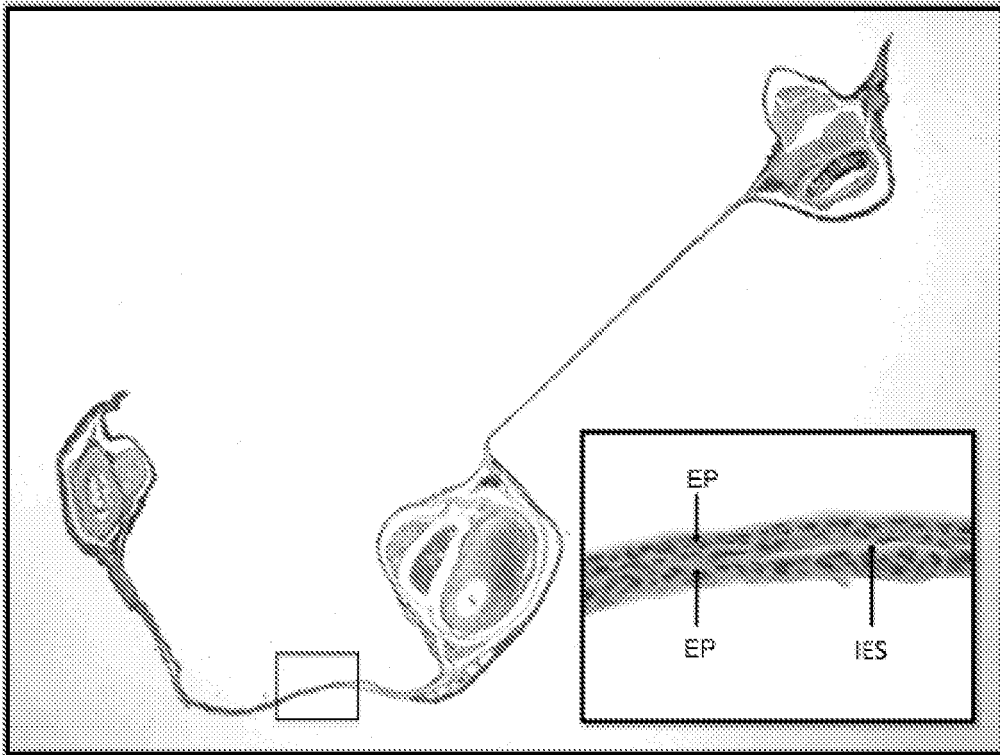
**FIG 3:**  
Relation of interdigital web between thumb D1 and index finger D2  
to insertion of Musculus abductor pollicis longus APL



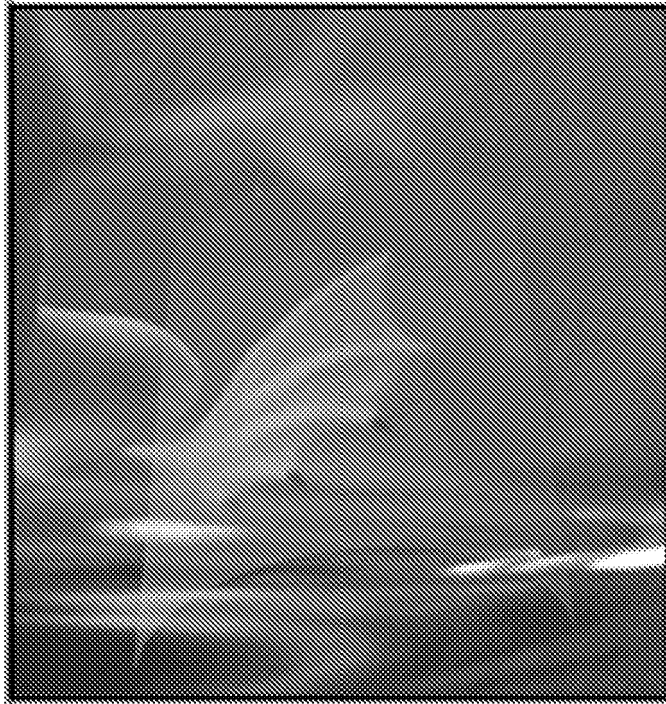
**FIG 4:**  
Relation of interdigital web IDW between  
thumb D1 and index finger D2 to area of insertion AI  
of Musculus abductor pollicis longus APL  
on Os metacarpale 1 MC1



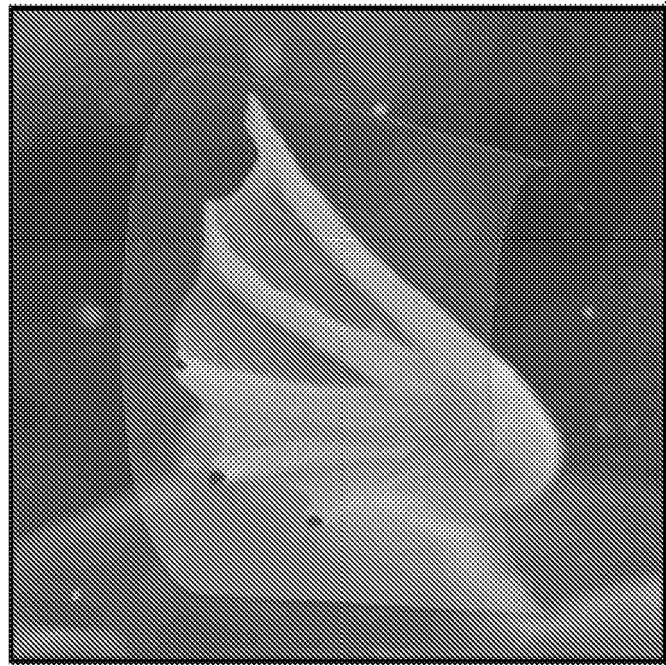
**FIG 5:**  
Phalangeal bone PB, Epithelium EP, Interepithelial space IES  
Xenopus laevis: foot, coronal cut digital proximal, HE, 40X, insert 400X



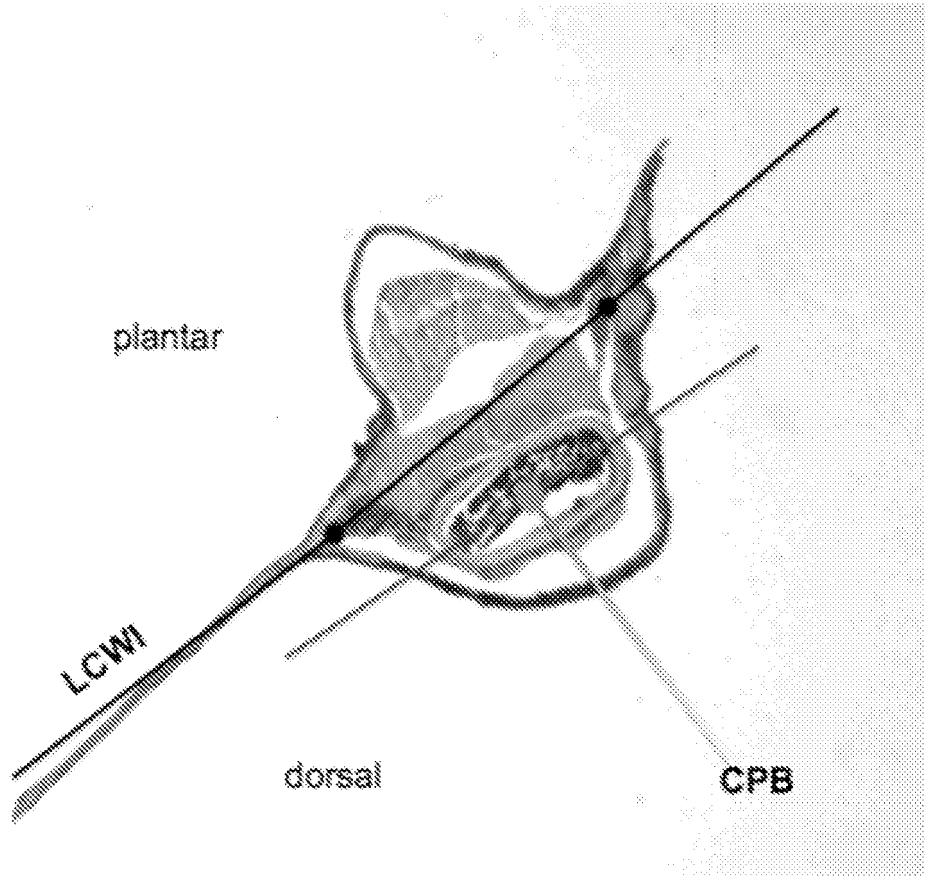
**FIG 6:**  
Epithelium EP, Interepithelial space IES  
Xenopus laevis: foot, coronal cut digital distal, HE, 40X, insert 400X



**FIG 7:**  
Interdigital web curved  
*Xenopus laevis*



**FIG 8:**  
Interdigital web curved  
*Xenopus laevis*



**FIG 9:**  
Line connecting web insertion LCWI, Center of phalangeal bone CPB  
Xenopus laevis: foot, coronal cut digital distal, HE, 40X

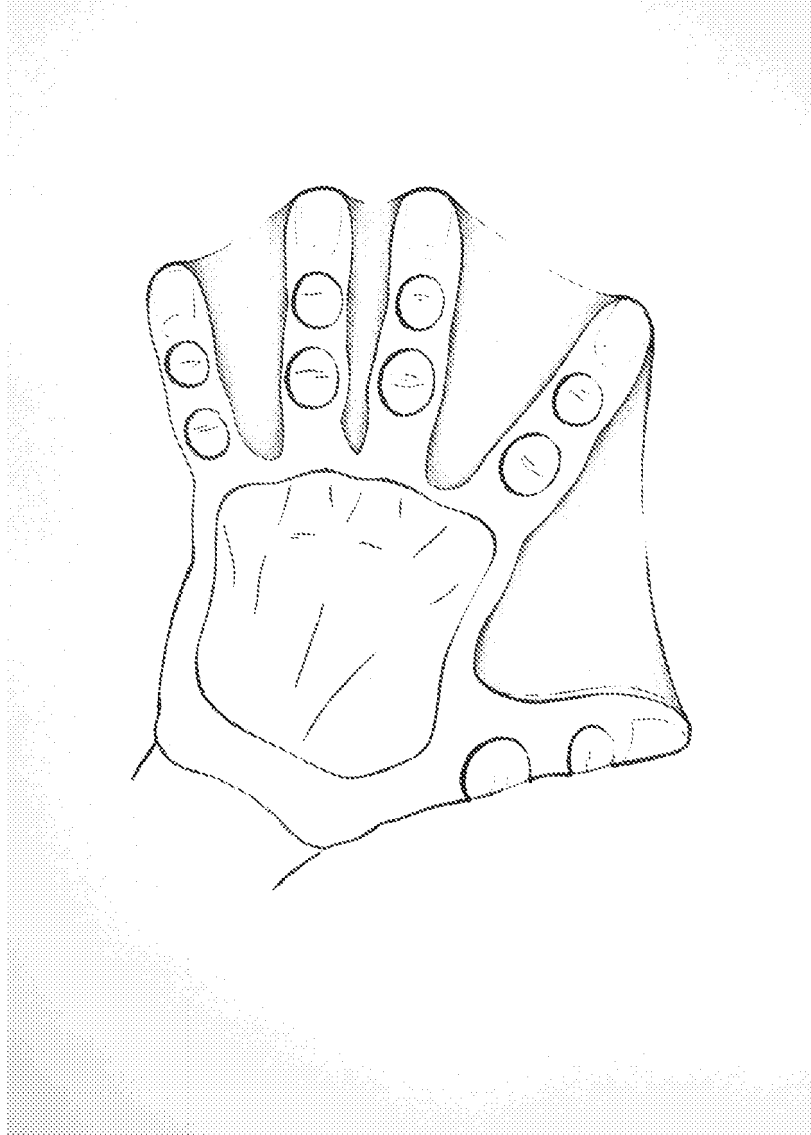


FIG 10

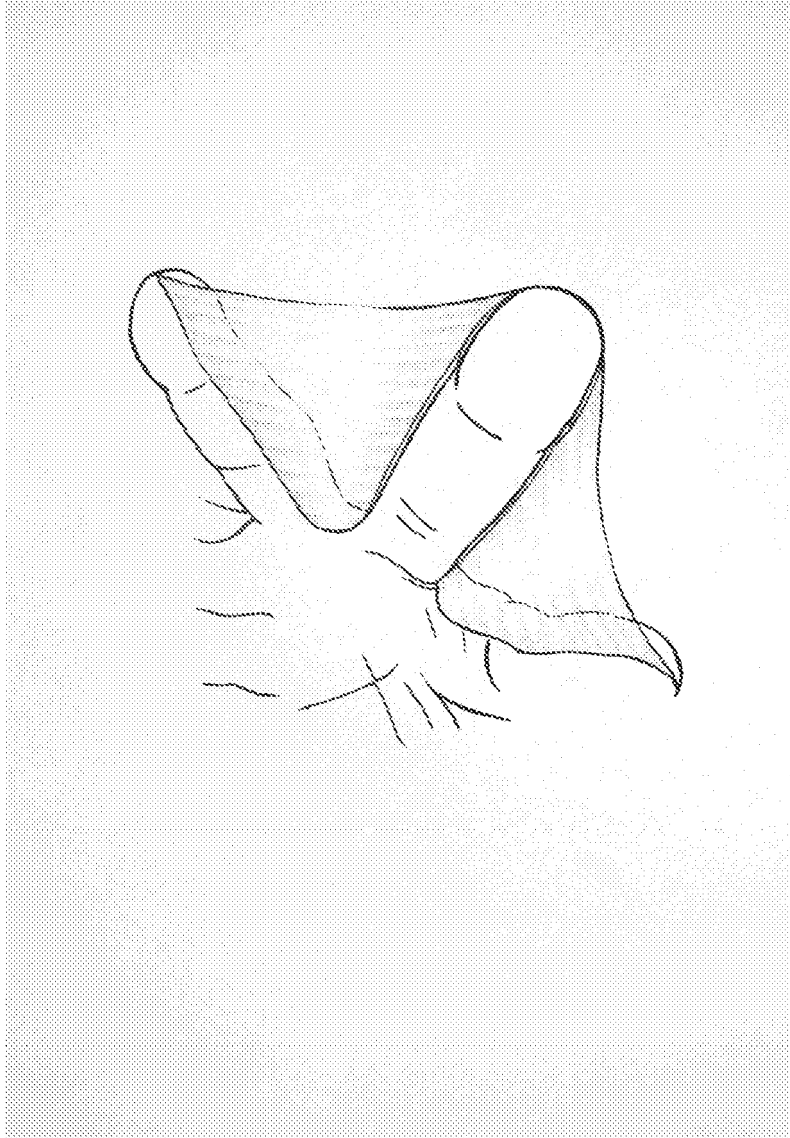


FIG 11

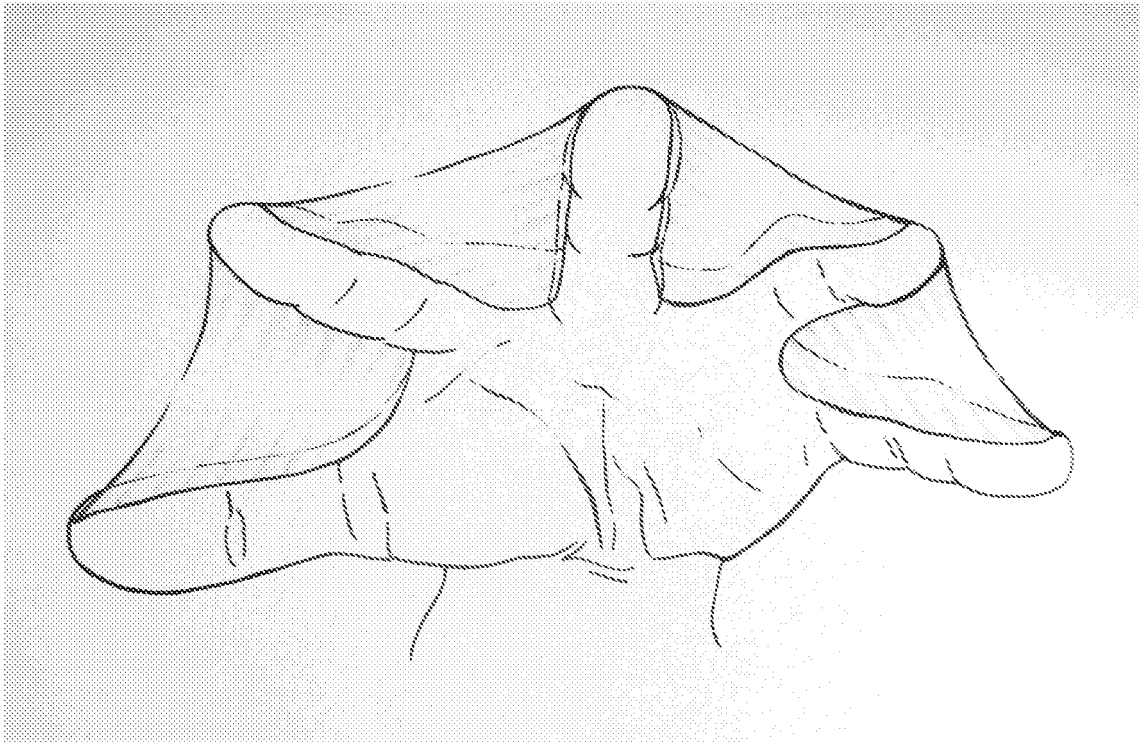


FIG 12

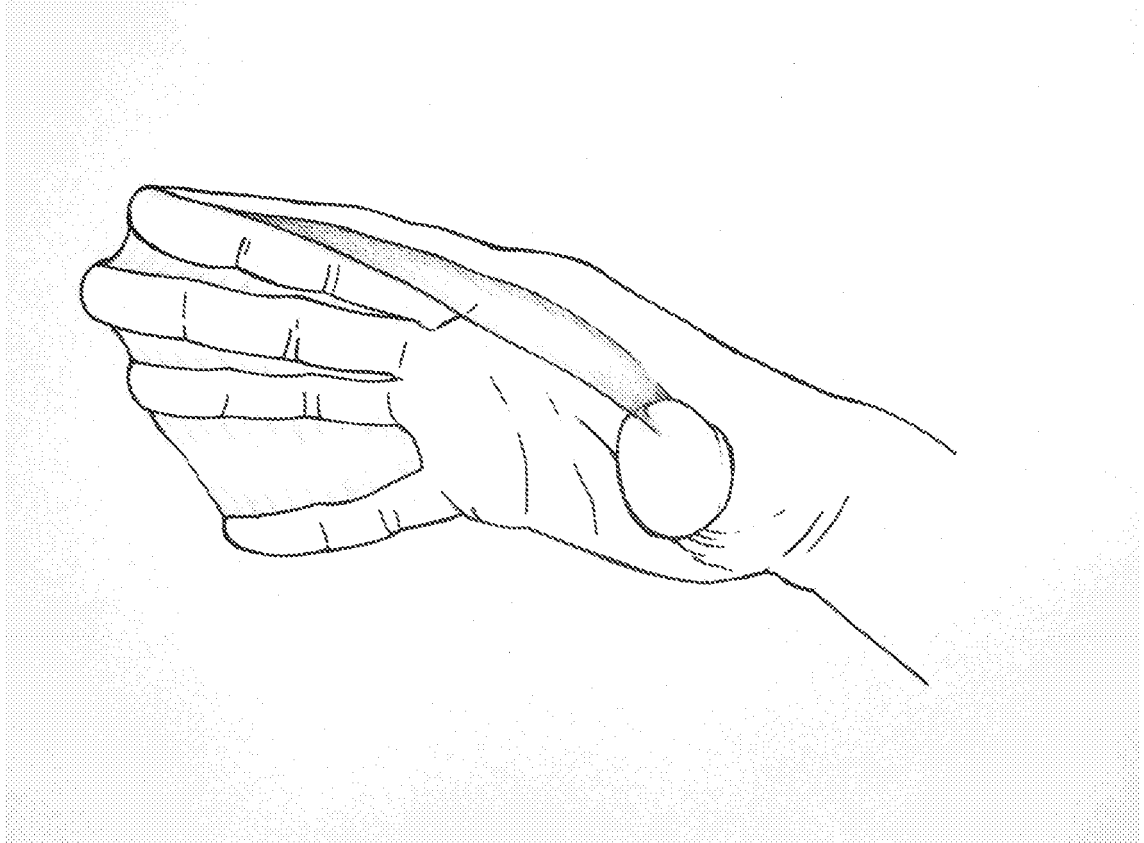


FIG 13



EUROPEAN SEARCH REPORT

Application Number  
EP 11 17 8554

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 4 618 328 A (CHI HSIN-HSIUNG [TW]) 21 October 1986 (1986-10-21) * column 1 - column 4, line 13; figures 1-5 *	1-5	INV. A63B31/04
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X	US 3 257 673 A (RADEMACHER ERWIN J) 28 June 1966 (1966-06-28) * column 1 - column 4, line 10; figures 1-6 *	1-5	
			TECHNICAL FIELDS SEARCHED (IPC)
			A63B
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 6 January 2012	Examiner Oelschläger, Holger
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ..... & : member of the same patent family, corresponding document	
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06-01-2012

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## REFERENCES CITED IN THE DESCRIPTION

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