73. Intelligent Textiles and Trends

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Textiles are common materials for many medical applications. They are used, for example, as bandages, medical stockings, or scrubs. Developments during the last 10 years in the areas of wearable electronics, smart textiles and material research offer new possibilities to create medical textiles with a higher level of functionality and allow the development of completely new active medical textiles. This trend was made possible by the interdisciplinary cooperation of engineers and scientists from textile research, electronics, informatics, and mechanical engineering, together with medical experts.

The integration of electronic devices into textile base materials enables new possibilities for personal monitoring and therapeutical systems for sports and medical applications. Regarding the demographic development in industrial countries, such wearable monitoring devices may be very interesting in addition to common systems.

These new intelligent textiles are a result of the combination of textile and nontextile technologies. In addition to common textile properties, new functions will be realized by the integration of conductive leads. Besides the integration of common electronic components (e.g. sensors, amplifiers) in different clothes, the research activities focus on the development and application of textile and textile-based sensors and actuators.

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73.1 Textile Manufacturing Technologies and Applications

73.1.1 Textiles for Medical Application

Novel functional special textiles, resulting from the combination of textile and nontextile technologies, are an interesting alternative to the usual systems for medicine and medical technology. For example, by using different thread materials, textile and nontextile manufacturing technologies or coatings, common textile structures obtain a new level of functionality.

In addition to known applications of functional medical textiles like compression textiles, scrubs, or antidecubitus systems, active medical textiles offer new applications like the identification of hospital clothing by textile RFID tags for industrial laundry or

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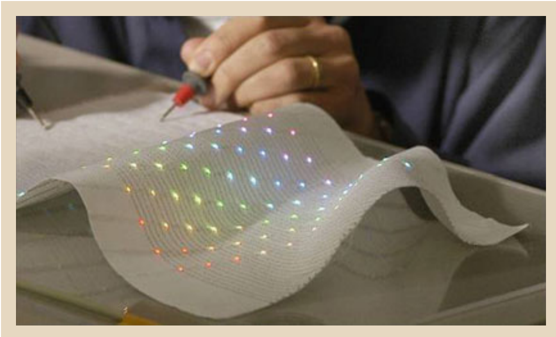

Fig. 73.1 Woven LED structure (Philips, Lumalive; TITV Greiz)

the monitoring of vital parameters by textile-based sensors. These so-called smart textiles are made of a textile base structure and, for example, electronic devices.

In addition to the common textile properties, new functions will be realized by the integration of conductive leads. Besides the integration of common electronic components (e.g. sensors, amplifiers) in different clothes, the activities of different research institutes are concentrated in the development and the application of textile and textile-based sensors and actuators. The base of such developments is, beside other materials, a conductive thread material. One example for a commercial product, which was developed at TITV Greiz, is the so-called ELITEX material. By the combination of electronic and textile typical properties, it can be used in all textile manufacturing technologies, like weaving, embroidery, or warp knitting. This is the first step for different product developments. Other attempts were made, for example, by using metal-based wires in combination with textile thread materials.

The goal is to integrate and not only to attach a non-textile technology into the textile structure to combine the advantages of textiles, like breathability, washability, stretchability, or a good wearing comfort with technical functions, like sensing or heating [73.1].

Textiles for medical applications can be separated into

- Functional medical textiles
  - Wound treatment
  - Compression textiles
  - Antidecubitus systems
  - Implants
  - Filtration
  - Hygienic textiles
  - Electromagnetic shielding
- Active medical textiles
  - Medical agent depot and disposing systems
  - Monitoring textiles, textile-based sensors
  - Therapeutical electrodes, e.g. functional muscle stimulation
  - Electrode systems
  - RFID tags
  - Heating and cooling textiles for thermotherapeutic applications.

A short overview of textile manufacturing technologies is given in the following sections.

73.1.2 Weaving

Woven fabrics are produced by right-angled crossing of at least two-thread systems, named warp and weft. The warp threads move in a lengthwise direction through the loom. The thread are lifted or lowered in a defined order (pattern) by a shedding machine (Fig. 73.2).

Then the weft thread is inserted. This can be done by a projectile, a rapier or by air. After that the weft thread is fixed at the woven fabric end. The high and low position of the warp threads now changes for the next weft insertion. This change is carried out by a dobby machine, where several threads on one frame make the same pattern. By using a jacquard dobby it is possible to control each warp thread individually.

Typical applications of weaving technology for the realization of smart textiles are multilayer structures for energy and data lines, antennas, textile electrodes, or photonic/light emitting textiles. These photonic textiles can be realized by the integration of LEDs in the textile structure (Fig. 73.1).

With a high density of threads up to 120 per cm multilayer matrices e.g. conductive boards can be created.

73.1.3 Embroidery

In the traditional definition, embroidery is a technique of decorative needlework in which designs are created by stitching strands of some material onto a layer of another material.

Up until now, most embroidery used textiles threaded stitches onto a woven or nonwoven fabric, but recently embroidery has become more and more important in technical applications ranging from fiber reinforcement up to electronic circuits. Stitches can

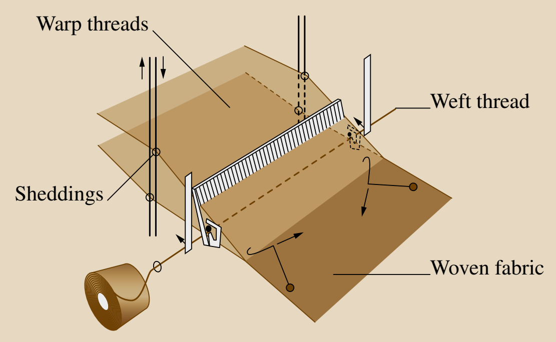

Fig. 73.2 Weaving machine with sheddings, schematic (TITV Greiz)

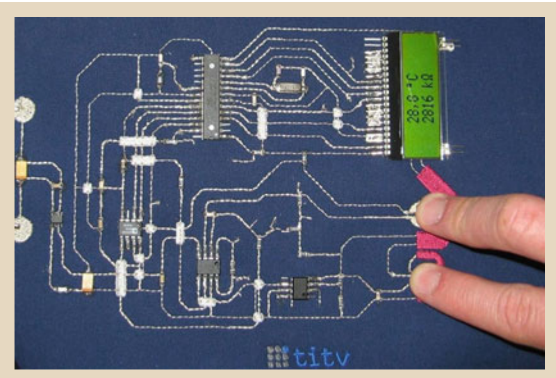

Fig. 73.3 Embroidered conductive circuit board (after [73.3], TITV Greiz)

be executed in wires and embroidery can be worked onto nontraditional materials such as plastic foils. One unique feature of embroidery is the possibility of placing stitches in any desired direction forward, backwards, and sideways. Very complex multilayer patterns, like conductive circuit boards (Fig. 73.3) can be produced in this way [73.2].

For the realization of embroidered structures two main principles exist. On the one hand, a thread is stitched onto a base material and fixed by a second thread from the lower side of the textile material (two-thread system). On on the other hand, the functional thread can be fixed on the base structure (soutage technology) by two separate threads, compared to the two-thread system. Tubes, wires, carbon, or glass fibers can be fixed onto textiles with the soutage technology, for example.

Besides the fixation of fibers and threads it is also possible to fix and to interconnect electronic components (Fig. 73.4). With embroidery technology the components can be fixed mechanically and the electronic interconnection can also be achieved.

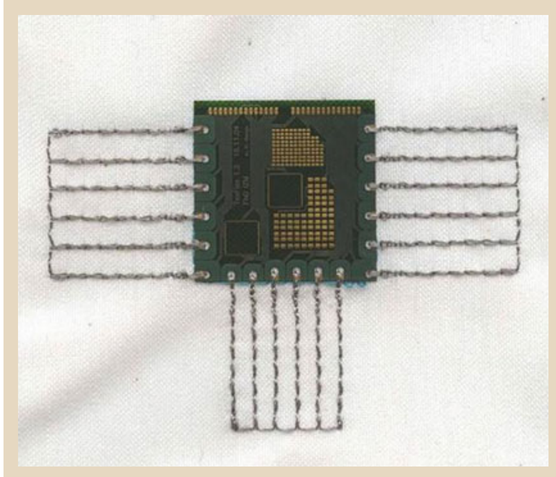

Fig. 73.4 Flex-foil substrate fixed and connected by embroidering technology (after [73.4], TITV Greiz)

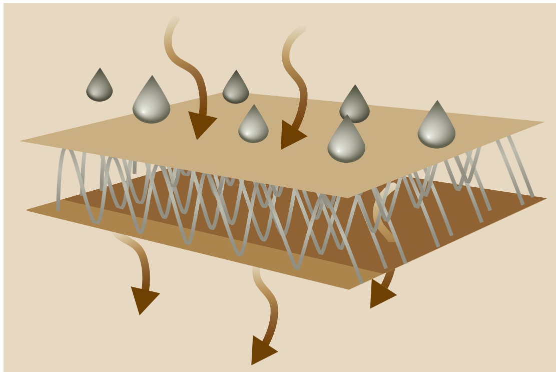

Fig. 73.5 Warp-knitted 3-D spacer fabric (after [73.4], TITV Greiz)

73.1.4 Warp Knitting

Warp knitted structures are special mesh structures. The fabric is created by the interloping of the yarns that are being knitted parallel to the length of the textile. A special type of warp knitted textile is the so-called three-dimensional spacer fabric (3-D spacer fabric). The 3-D spacer consists of two warp knitted surfaces that are connected and kept at a distance by third thread system – the pole yarn (Fig. 73.5). The two textile surfaces can be modified individually with respect to the binding or the materials used. Thus, the spacer fabric can be indi-

Fig. 73.6 Prosthesis pad in bras, cover made of spacer fabrics (after [73.4], TITV Greiz)

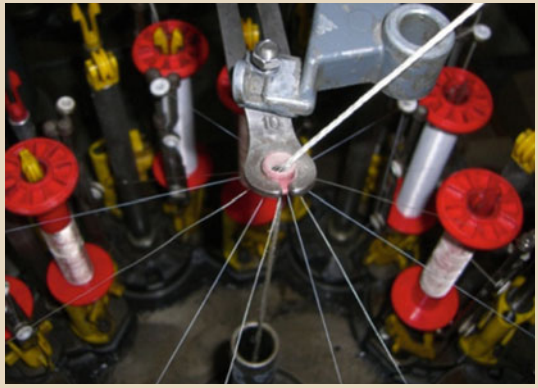

Fig. 73.7 Manufacturing of a braid (example) (TITV Greiz)

Fig. 73.8 Braid with sensor fibre as core material (TITV Greiz; ITA, Aachen)

vidually modified regarding the respective applications. For example, the thickness can be varied from 1.5 mm up to 60 mm.

The typical properties of the spacer fabrics are:

- Pressure stability and good pressure distribution
- Moisture transport by special thread materials in the upper and lower surface
- Good thermal & air circulation and good thermophysiological properties.

Because of the good thermophysiological properties of the spacer fabric, the material is used in several medical applications, e.g. the lining of orthesis or prosthesis pads (Fig. 73.6) in bras. Further applications are compression bandages, antidecubitus mattresses, insoles, or hip protectors.

73.1.5 Braiding

A braid is manufactured by interlacing three or more threads forming a flat or tubular narrow fabric. The yarn is directly fed from the rotating bobbins (Fig. 73.7) to the braiding point. Defined by the movement of the clappers to one another the binding, and thus the structure, of the braids can be varied. The dimension of a braid depends only on the count of the yarn, the number of threads, and the type of binding [73.2]. Braids can be used, for example, for energy transfer by using metal wires or litz wires.

Currently, two main variants of tubular narrow fabrics exist. A thread or another material can be placed inside the braid during the manufacturing process. The reinforcement of tubes or the shielding of a conductive thread or wire are typical applications. It is also possible to manufacture a braid without inner core material. Artificial vessels are typical medical applications for these types of braids. Other medical applications of braids are tendon replacements or surgical sutures. For example, PVDF braids are combined with titanium screws for the fixation of artificial tendons [73.5].

With the integration of nontextile materials in the braiding process new applications are possible. Figure 73.8 shows a bending angle sensor. Sensor fibers are integrated in the braid during the manufacturing process.

Besides the described structures braiding technology can also be used to create complex three-dimensional structures e.g. for fiber composites. Complete fiber reinforced components, for example for the aircraft industry, can be produced with 3-D braiding manufacturing machines [73.6].

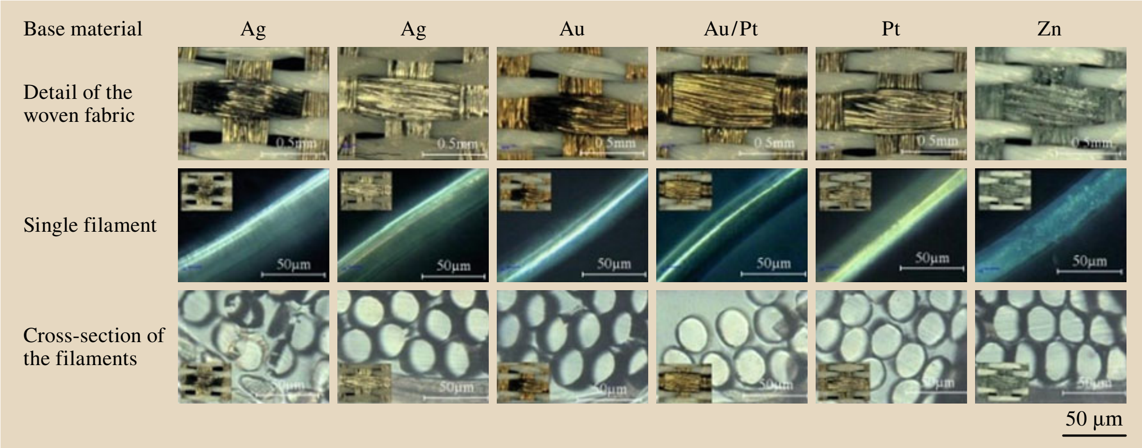

Fig. 73.9 Overview of different ELITEX variants, base material (Ag, Statex) is galvanized with silver (Ag), gold (Au), platinum (Pt) and zinc (Zn) (TITV Greiz)

73.1.6 Conductive Thread Materials

The basis for the integration of sensor and electronic devices in textiles is a conductive thread material. Actually, there are different strategies and materials to realize the transfer of data and energy in textiles. On the one hand, there are different possibilities to use common copper or steel fibers to integrate electronic parts in textiles. Some of them can be used in a regular textile process, e.g. weaving. Often there are some problems with the long-term stability of these metallic materials. If these threads are bent many times, for example, during the wearing or washing process they can break. On the other hand there have been many attempts to create conductive textile threads. They have the advantage of a very high stability against bending and low weight. However, normally it is not possible to use these structures as data lines for low-volt signals. The resistance of these materials is too high. Typically, these threads are used as energy lines, e.g. for textile heating systems. Different strategies are pursued to reduce the resistance without losing the advantage of low weight and flexibility.

One possibility is the new galvanization process, developed by the TITV Greiz, Greiz, Germany, to handle textiles. By different electrochemical processes a silver-coated polyamide fiber is again galvanized with a silver coating. So it is possible to reduce the resistance of the base material from about 700–800 Ω/m to 15–20 Ω/m (base yarn count of 235 dtex). The final value depends on the material applied (Fig. 73.9) and the type of finishing process of the yarns. For example, a different number of threads can be twisted together so the resistance can be minimized. Woven structures with a resistance of about 1 Ω/m can be realized with these yarns [73.2, 7].

By additional coating processes these conductive threads can be insulated e.g. by a TPU or PVC coating (Fig. 73.10). Another possibility is the coating of the manufactured textiles, e.g. narrow fabrics in which the conductive threads have been integrated (Fig. 73.11).

To realize stable electronic interconnections, different strategies have been used. For example the material can be soldered (Fig. 73.12) or glued under special conditions and it can be crimped with adapted tools. This is an important factor for the industrial implementation of smart textiles.

Fig. 73.10 Insulated ELITEX thread (TITV Greiz)

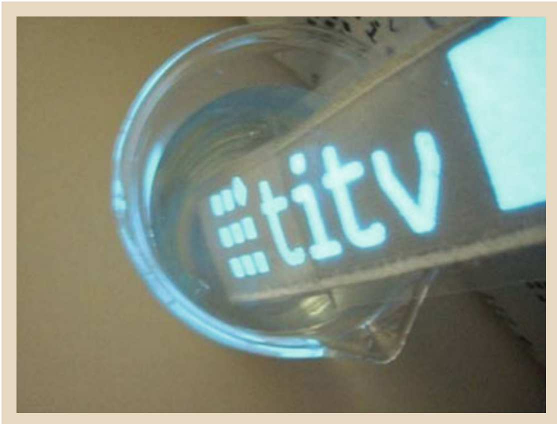

Fig. 73.11 Photonic textile, conductive narrow fabric, water resistant insulation by coating (TITV Greiz)

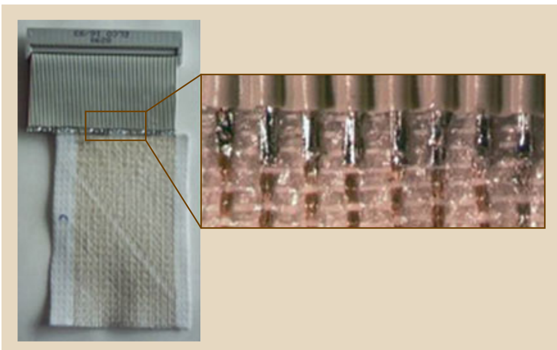

Fig. 73.12 Soldered interconnection between commercial IDE cable and woven bus structure (TITV Greiz)

Fig. 73.13 Core mantel thread construction of textile and metallic components (TITV Greiz)

Besides the use of galvanized thread materials, other possibilities to create conductive yarns or fibers also exist.

Examples are:

- Metal Fiber yarns
- Metal wire/textiles yarn construction (Fig. 73.13)
- Metalized yarn, e.g. by chemical or PVD processes
- Carbon fibers
- Fibers filled with conductive particles, e.g. silver, carbon, ICP or CNT particles
- Fibers with a conductive preparation
- ICP (intrinsic conductive polymers) fibers
- CNT (carbon nanotube) fibers.

It depends on the application and the available manufacturing technology which material should be used.

73.2 Sensory Applications of Textiles

73.2.1 EMG and ECG Monitoring

The monitoring of parameters like EMG or ECG is very important for different medical and sports medical applications from the preventive or therapeutical points of view. For surface EMG and ECG electric body signs are recorded by glued, plastic, or metal permanent electrodes separately fixed on the skin. The wearing comfort of these electrodes can be estimated as unsatisfactory for patients, especially during long-term applications. The displacement of the electrodes caused by physical activity and sweat development between skin and electrode is a common reason for wrong measurements. In some cases, the electrolytic gel causes skin irritations.

Reliable monitoring systems are required without negative influence to the wearing comfort especially in the fields of medical care and therapy, sports, and occupational medicine.

The combination of textiles as a flexible and light material with foreign technologies opens new ways to create new intelligent products for body-closed applications for medical and medical technique applications. This includes the integration of conventional sensors and sensor systems in different pieces of clothing, but also the development of textile and textile-based sensors [73.8].

Currently there are several approaches to integrate a monitoring system in vests or shirts. Research insti-

Fig. 73.14 MμGuard monitoring vest monitoring vest with silicone based dry contact electrode (after [73.10])

Fig. 73.15a,b ConText vest with textile-based contactless electrodes. **(a)** Prototype II, **(b)** final prototype (after [73.8])

tutes and industrial companies are working on these topics in several national and international research projects. The systems Life-Guard, SmartShirt, Vital-Jacket, LifeShirt and MμGuard are only a few examples of these aspirations [73.9, 10].

These monitoring shirts are designed for long-term monitoring. One aspect to increase the comfort of the wearer is the use of flexible dry electrodes. Conductive silicone-based electrodes are a promising strategy [73.13].

Textile electrode systems can work by direct skin contact or alternatively without contact by capacitive coupling.

There are currently two main strategies to monitor EMG and ECG signals. The electrical current can be measured by contact electrodes and noncontact electrodes. In the first case, a conductive textile structure (Fig. 73.16) can be used to measure the electric signals. The quality of the signals depends on different aspects, e.g. the contact area, the structure of the electrode and the surface, and inner conductivity. Normally the textile electrodes need to be moistened by sweat or special contact gels. Currently, there exist different strategies to coat the conductive thread materials by conductive polymers or ionic liquids. First results are promising [73.11].

In the second case, the idea is to monitor the EMG and ECG signals by noncontact electrodes. In different research projects the idea of a noncontact ECG monitoring has been investigated. Besides the design of the electrodes there are special requirements referring to the electronic components, the shielding, and the analyzing process [73.14, 15].

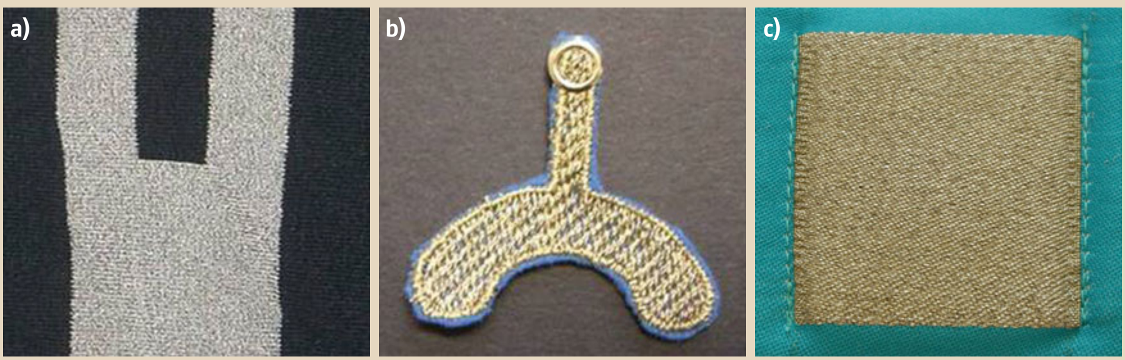

Fig. 73.16a–c Textile electrodes. Examples **(a)** knitted, **(b)** embroidered, **(c)** woven structure (after [73.11, 12], TITV Greiz)

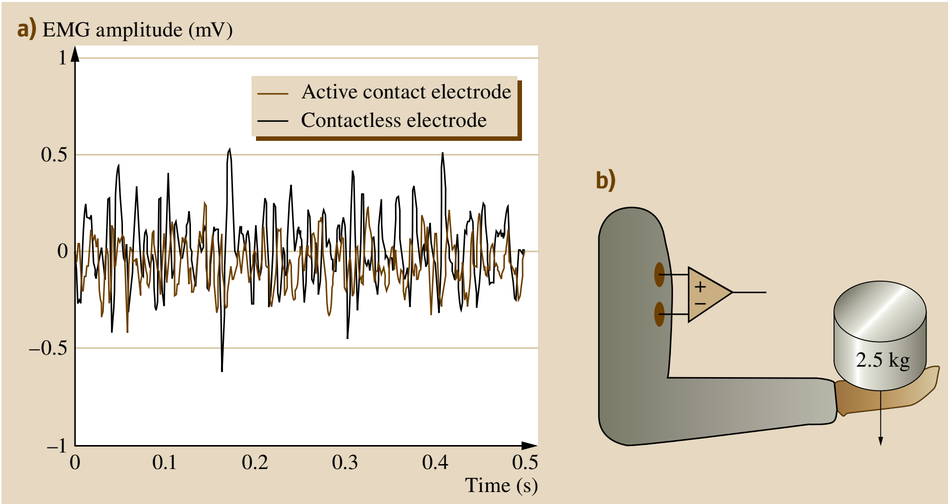

Fig. 73.17 (a) Recorded EMG signals with both an active and (b) contactless electrode (after [73.17])

In the EU research project ConText (IST-027291), TITV Greiz worked together with the project partners Philips Electronics Nederland BV (NL), The Catholic University of Leuven (B), Technische Universität Berlin (D), Clothing Plus Oy (FIN), and the Netherlands Organization for Applied Scientific Research, TNO (NL) on the contactless recording of EMG and ECG signals using only several textile and textile-based capacitive sensors with the relating electronic devices [73.16]. The textile sensors in the ConText project were manufactured by weaving, embroidery, printing, and lamination technology. The final prototype of the sensor consists of a laminated structure and woven fabrics for energy and data transfer.

Another possibility for the realization of such a sensor fabric lies in different woven multilayer structures. So it is, for example, possible to create a textile capacitor that can be used as the sensor area. It consists of two conductive layers of ELITEX material that are insulated by two textile layers in the middle. The capacitance of the fabric can be adapted by changing the conductive thread material or the linkage. By a special type of weaving it is also possible to integrate the connectors for the data transfer.

The measuring principle is similar to the contact electrode of a pair of electrodes. These electrodes are built by two conductive layers that are separated by an insulating layer and work as a capacitor. Such a configuration can be used to connect the biopotential signal capacitively to an amplifier. In practice, two electrodes are used and connected to a differential amplifier. The differential signal is then sent to the measurement system to be sampled, processed, and analyzed. Figure 73.17 shows some results of the comparison of common contact and the first prototypes of the contactless electrodes.

For a real integration of various electronic devices in a textile structure, it is necessary to use textile or textile-like bus structures for the transfer of energy or data. These structures should have mechanical qualities that are comparable to those of base textile, e.g. a shirt or a vest. The woven structures are made of a special multilayer design, which allows the creation of conductive lines of insulated layers on the upper and lower sides. These narrow fabrics can be used for analog and digital data transfer. For sensible measuring applications it is also possible to create shielded bus structures. By means of a special weave it is also possible to create flexible textile narrow fabrics with integrated conductive threads. A very high strain rate is realized without a change of the electric resistance in contrast to other commercially available materials. The resistance of these normally used materials depends on the stress rate. Because of the changing resistance it can be difficult to use these materials for data lines, especially if it is necessary to transfer low-level or low-voltage signals. There are no problems with these new elastic conductive structures. They can be used in elastic clothes, for example. So the stress–strain behavior of the clothes will not be influenced by nonelastic structures, and the stress will not influence the resistance of the bus structures.

Besides the monitoring of EMG and ECG, these sensors also provide information about the physical and

Fig. 73.18 Textile-based capacitive EMG electrode, ConText project (after [73.11])

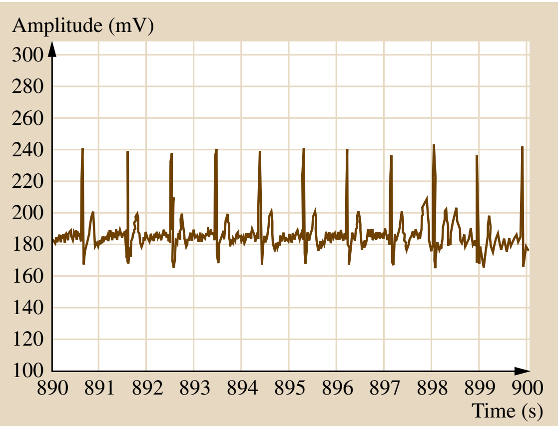

Fig. 73.19 ECG – Signal measured with contactless capacitve electrode (after [73.11], Context project)

mental stress level in addition to the general muscle potential by special algorithms [73.16, 17].

73.2.2 Respiratory Monitoring

Reliable respiratory monitoring is very important for different sport and medical applications. Besides the respiration rate, additional parameters exist, e.g. the breath volume, which deliver important information about the training condition or the sleep behavior of the sportsman or patient.

Different technological possibilities can be used to monitor respiration. The spectrum ranges from simple elongation measurement to monitoring the respiration rate up to the 3-D bioimpedance spectroscopy of the thorax to obtain detailed information about the breath volume and the health status of the lungs e.g. fluid re-

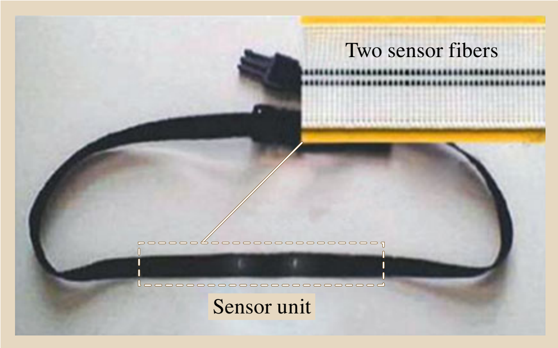

Fig. 73.20 Respiratory monitoring belt (after [73.18], TITV Greiz)

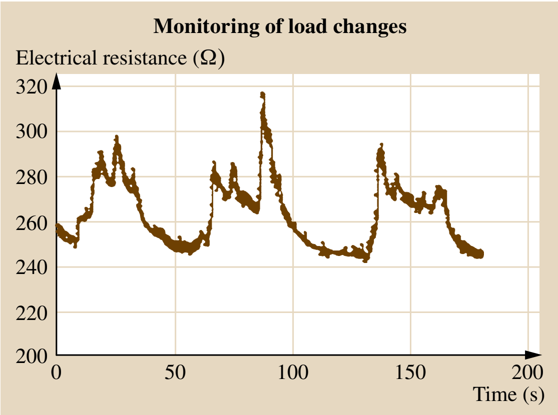

Fig. 73.21 Respiratory monitoring, results (examples) (TITV Greiz)

tention in the lungs. The type of the measuring principle depends on the medical indication.

A very easy and comfortable way to monitor only the respiration rate is the integration of an elongation sensor in an elastic belt or a shirt. The sensor system is limited to only a few electronic components that can be integrated into textiles without influencing the wearing comfort.

The respiratory monitoring belt shown in Fig. 73.20 is composed of an inelastic belt, which can be easily fixed on the thorax, and a sensor unit. The sensor unit is an elastic narrow fabric with integrated sensor fibers. A carbon filled rubber is used as sensor fibers. In the form used here, this material has a nearly linear elongation specific resistance. By inhaling, the change in the resistance can be measured through the sensor's elongation. The peaks in Fig. 73.21 show the moments of the maximum elongations. With an additional electronic device it is very easy to measure the respiration rate by measuring the change of resistance. A calibration modus at the beginning of the measuring process can be done at maximal and minimal thorax status.

For reliable monitoring it is very important to use a weave that enables a stable fixation of the sensor fibers in the narrow fabric. The narrow fabric and the sensor fibers should be configured in such a way that they always work in the elastic elongation range in order to obtain long-term stable results.

Such an easy monitoring system may be integrated in different clothes as well as heart rate monitoring belts, e.g. the Polar WearLink (by Polar Electro Oy, Finland) and may deliver additional results during sports, stress tests, or during sleep.

73.3 Active Textiles – Therapeutical Applications

73.3.1 Textile Electrodes for Electrical Muscle Stimulation

Besides the integration or adaption of sensoric functions, conductive textiles provide the possibility to build up actuatory systems, like heating devices or textile electrodes for electromyostimulation.

The effect of electricity for medical purposes, specific muscle formation among sportsmen, or for rehabilitation aspects is known today. Electrotherapies use the different effects to the human organism. The main applications are pain therapy and muscle stimulation for training effects. For electrostimulation, metal electrodes or adhesive Ag/AgCl electrodes, which can only be used a few times, are fixed onto the skin at defined spots by therapists or the patients themselves. This can be difficult and uncomfortable, especially near the extremities due to perspiration under the surface of the electrodes and leads to reduced wearing comfort and effect. To improve the wearing comfort and effect, TITV Greiz developed a new system of electrodes on the basis of conductive yarns. It was integrated in several textile elastic garments like track pants and shirts and improved wearing comfort was achieved.

To reduce the contact impedance between the skin and the electrodes, different finishings and preparations were tested on a technical skin model and with test persons by electrochemical impedance spectroscopy (EIS) [73.1, 11].

Common textile tests like wash stability and tests against abrasion and sanitizing ability were combined with electronic tests regarding the homogeneity of the conductive areas.

In cooperation with the Institute of Physiotherapy of the Friedrich Schiller University of Jena, Germany, these textile electrode systems were tested for the stimulation of femoral muscles. Textile and classic (glued) electrodes were compared with respect to their therapeutical effect during different applications, like transcutaneous electrical nerve stimulation (TENS), electrical muscle stimulation (EMS), or electromyogram (EMG) as biofeedback. Besides the parameters of

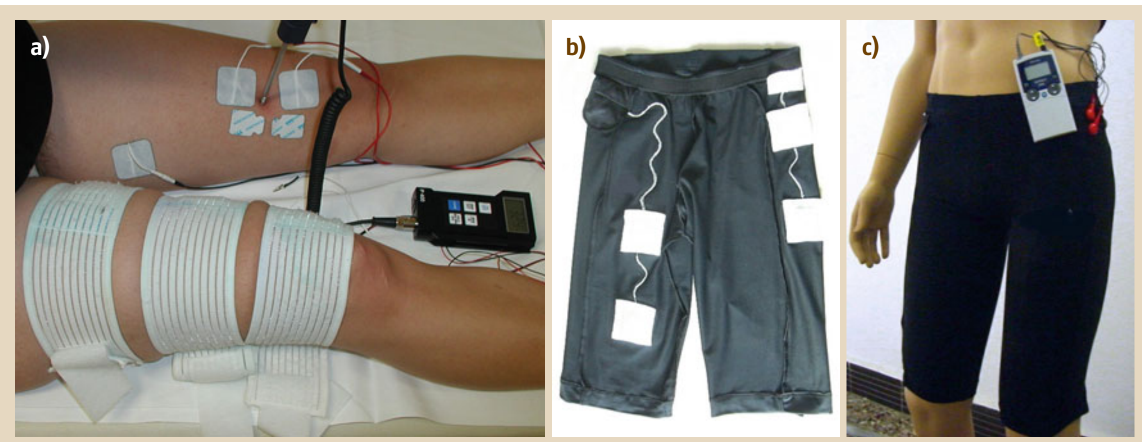

Fig. 73.22 **(a)** Test person with textile and glued electrodes [73.12]. **(b,c)** Prototype of a stimulation system for the femoral muscles (after [73.8], TITV Greiz)

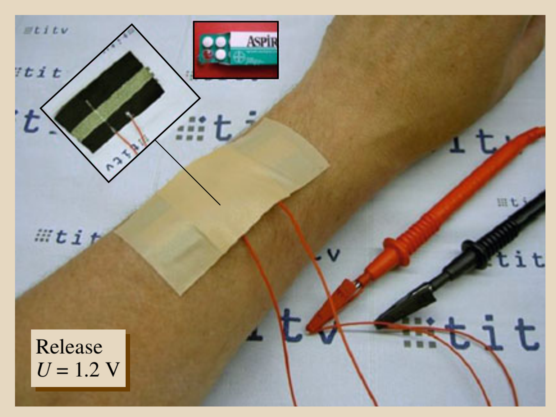

Fig. 73.23 Basic implementation of the interactive fabric structure in an interactive textile TTS (TITV Greiz)

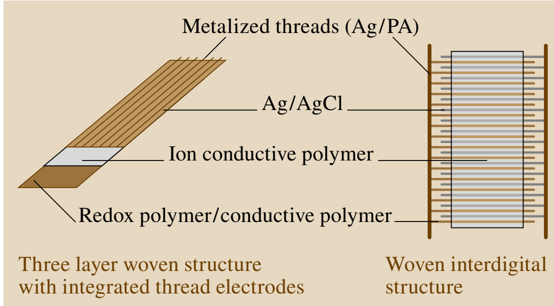

Fig. 73.24 Electrochemical modified thread electrodes as an interactive drug store and delivery systems (principle) (TITV Greiz)

the electronic therapy devices, different parameters like skin resistance, skin temperature, and the subjective impression of the test persons were registered. The results of the first study with 25 test persons show a comparable behavior of the common and the new textile electrodes. A target of further developments is the certification of the textile electrodes as a medical product class 2a [73.11, 12].

73.3.2 Textile Interactive Medical Agent Depots and Disposing Systems

The storage and controlled release of pharmaceuticals in the form of transdermal therapeutical systems (TTS) offers interesting alternatives to conventional pharmaceutical delivery in the form of tablets or injections. In addition to bypassing the digestive tract by the direct transition into the blood vessels and the associated lower dose, transdermal systems are easily applicable.

Furthermore, the patient's acceptance increases because the distances between the application forms are much higher in comparison to other pharmaceutical types. The dose is only determined by the type of storage of the pharmaceuticals in the support material. So, the danger of misuse is reduced to a minimum. Typical applications are analgesics (e.g. morphine in long-term applications), or nicotine.

In addition to the benefits of TTS some disadvantages also exist. Insufficient breathability and low moisture transport are two aspects. This can lead to occlusion of the covered skin areas, thereby favoring the occurrence of skin irritations. Furthermore, there are problems with the adhesive strength of the plaster, which are reduced during the application time. The plaster can also become detached during washing or during physical activity.

Another disadvantage during the application is the start of the release process by removing the protection layer (release liner) of the system. Once the system has fixed on the skin, the release process starts and will not end until the storage is empty or the whole system is removed.

Textile multilayer woven fabrics with different thread preparations e.g. conductive, redox, and ion conductive polymers have been investigated as one possibility of creating interactive textile base structures (Fig. 73.23) that can be used as an agent depot and delivery system. During the many experiments it was found that redox polymer modified ELITEX materials can store agents as anions that are chemically bounded on the polymer chain. The anions can be interactively electrochemically released again by applying a voltage or an appropriate reducing agent. By a suitable textile construction it was possible to create first prototypes of a textile pharmaceutical store and delivery system (Fig. 73.24). It is possible to store and release between 50 mg and up to 500 mg acetylsalicylic acid with such a structure [73.4, 7]. These interactive textile structures can be considered as first steps to textile-based interactive transdermal therapeutical systems. The developed prototypes could be combined with additional iontophoretic electrodes for a defined transfer of the released active ingredients through the skin.

73.3.3 Heatable Textiles for Therapeutic Treatments

Textile-based heating systems were one of the first developments in the area of active textiles. Several com-

Fig. 73.25 Thermal treatment bandage with controller, lumbar bandage (after [73.19], TITV Greiz)

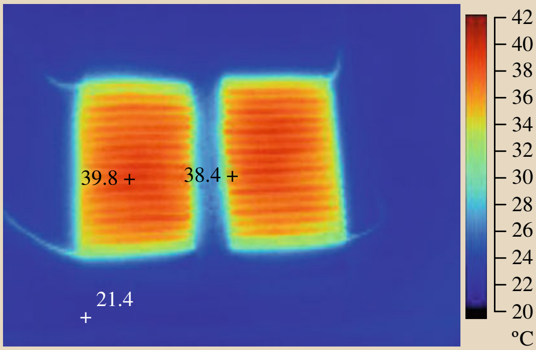

Fig. 73.26 Thermal treatment bandage, temperature distribution (after [73.19], TITV Greiz)

mercial products are already available. Mostly, these heatable textiles are used in sports applications e.g. snow boots, gloves etc. Usually combinations of metal wires, carbon fibers, and metalized fabrics are used in these applications.

Heatable Bandages for Therapeutic Treatment

Besides these commercial or sport applications, textile heating systems can also be used for therapeutical aspects. Among them, thermal treatment methods are the oldest and most commonly used therapies. The attainable effects range from a general improvement of well-being and mental relaxation to the locally defined influence of muscle tone, circulation, inflammation, pain, and the influence of the hormonal and the immune system. Thermal applications show a great diversity, which is multiplied by various application techniques. The whole body or only certain parts of the body are heated up. The heat can be applied in such a way that only the body surface or the deeper tissues are heated up. The application time can vary between 10 and 60 min.

Recent medical research results show that thermotherapeutical applications with temperatures between 37 and 45 °C and an extended period of use are very effective. Many of the applications in this area are not mobile or transportable. Therapeutical applications where the patient can move freely often have disadvantages in the dosage of the heat and the wearing comfort.

Figures 73.25 and 73.26 show a lumbar bandage for thermal treatment. It consists of an elastic bandage, two textile heating modules, and the controller device.

The heating modules are woven narrow fabrics with integrated electrical insulated heating threads. In contrast to other production technologies, the integration of the heating fibers is done directly during the manufacturing process of the narrow fabric. Thus, the textile properties e.g. flexibility and drapability, can still be retained.

The modified manufacturing process allows the integration of the heating threads regarding the defined requirements, e.g. distribution and quantity of heat, power supply, and electronic connection [73.19].

The result is a mobile bandage for thermal treatment that meets the medical, electronic, and textile requirements. It is characterized by:

- A high wearing comfort
- Optical attractiveness
- Easy handling
- Nonstationary applications
- Enhancement of patient compliance = treatment results.

Heating System for Long-Term Operations

To keep the patient's body heated during an operation, different kinds of active principles are implemented: active and passive textile passive systems, as well as convective and conductive systems that are based on nontextiles.

An important trend is the combination of heating and pressure reduction. Especially during long-term operations local pressure strain in combination with moisture accumulation results in bedsores that not only bring consequential costs but are also an additional stress for the patient. Systems that include both functional principles can have many advantages in this case, not only economical ones. Three-dimensional structures (3-D spacer fabrics) have many advantages with respect to the prevention of bedsores, because especially three-dimensional knitted textiles are not only able to allow

Fig. 73.27 Spacer fabric heating structure, heating threads integrated in the pole area (after [73.12], TITV Greiz)

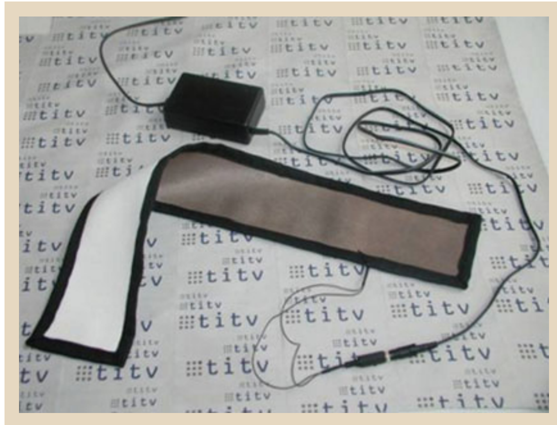

Fig. 73.28 Textile heating system based on a compound of 3-D-spacer fabric and a flat knitted heating device (after [73.4])

air permeability but also moisture transport due to their mesh structure. The proven pressure reducing properties of knitted spacer fabrics are, in this case, a sort of acceptable additional feature.

A wide range of electrical conductive materials for the integration in the spacer fabric's pole area have been investigated, such as multifilament wires, carbon wires, and metalized polymer yarns. Furthermore, possibilities for electrical contact have been investigated, whereupon the focus has been put on economical processes and reversibility.

The research work of TITV Greiz showed that the integration of heating wires into the spacer fabric's pole area without intermeshing must be stated as an optimum (Fig. 73.27). The adaption of the heating performance to the operation purpose, the free choice of the contact, and economical processing are convincing advantages [73.12].

By measuring the allocation of heat and temperature on the surfaces and determining the clothing-physiological properties, the samples proved their adequacy for applications in the field of medicine (hypothermia prevention) and also in the field of rescue missions (saving victims from cold areas). Along with a battery supported power supply in combination with a controller, mobile systems with the advantages of low weight, high flexibility, and reliability can be developed.

73.4 Passive Medical Textiles for Therapy

73.4.1 Reusable 3-D Knitted Elastic Short Traction Bandages

Three-dimensional (3-D) spacer fabrics are already being used as therapeutic means for decubitus prophylaxis in hospitals and care or as bedding material for orthopedic shoes. The goal of the project was the development of 3-D knitted elastic bandages with adjusted widths for medical applications, especially for the therapy of lymph edema. Particular attention was paid to reusability, economical handling of resources, and their recirculation to the value added chain.

Lymph edema diseases have an increasing tendency. An early and comprehensive treatment is important. Compression therapy is the only possibility to stop the disease from further diffusion. The method of choice here is the complex anticongestion therapy, which is characterized by an anticongestive first step (manual lymph drainage + special compression bandaging as flanking action) and a conserving second step to keep and optimize the success of treatment [73.20].

With the development of elastic 3-D short traction bandages costs and time can be saved. Better thermo-physiological conditions, the prevention of thermal congestion and optimal breathability help the patients to improve their quality of life. Economical as well as ecological effects are achievable. The new elastic 3-D bandages (Fig. 73.29) are totally different from the products and materials known so far. Two textile outer surfaces and an aired zone between make these ban-

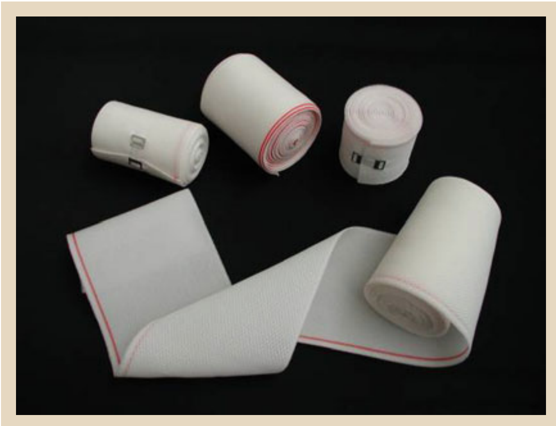

Fig. 73.29 3-D-knitted elastic short traction bandage (after [73.4], TITV Greiz)

Fig. 73.30 Patient with 3-D-knitted elastic short traction bandage and fixed pressure sensor (TITV Greiz)

dages not only compressible but also cushioning. The bandage of edema patients can be realized with a simplified wrapping technique and without any cushioning with comparable efficiency.

The manufacturing technology with a double Raschel technique allows a number of bandages to be produced at the same time with different widths, specific materials and defined elasticity. So, favor-

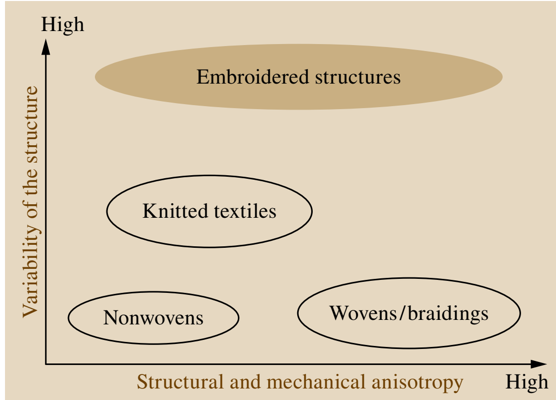

Fig. 73.31 Variability of embroidery technology compared to other textile manufacturing technologies (after [73.21])

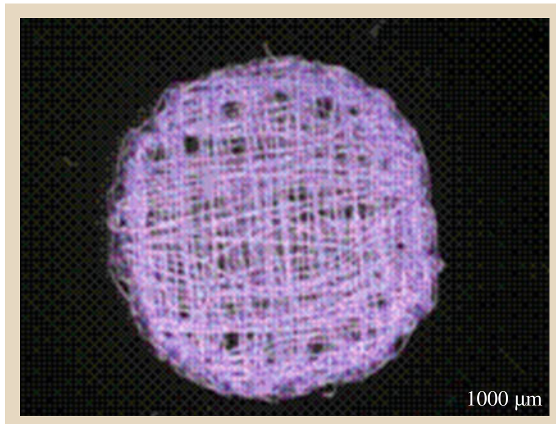

Fig. 73.32 Embroidered scaffold construction (after [73.1], TITV Greiz)

able conditions for the following processes (relaxation, washing, fixing) can be created. The test series included tests with different materials, weaves, mesh densities, and combinations of material. Elongation values as known from standard short traction bandages were achieved by the use of elastane and partial elastic bicomponent yarns.

Clothing-physiological and skin-sensory tests were made by BPI Hohenstein, Germany, with several 3-D bandages in comparison to standard bandages. It was shown that knitted materials made of spacer fabrics achieved a significantly better comfort note than the standard materials.

Application studies with medical staff showed that 3-D bandages have better handling and wearing comfort in comparison to standard bandage materials

(Fig. 73.30). Although the bandages are more voluminous, an easier wrapping technique was pointed out.

This development is an interesting alternative for bandages, especially for patients with lymph oedema during the complex anticongestion therapy [73.22].

73.4.2 Embroidered Implants for Tissue Engineering

Embroidery is an interesting alternative for the development of three-dimensional textile-based implant constructions like scaffolds and patch grafts for tissue engineering. According to the principle of chemical embroidery, it is possible to create individual and application related scaffolds and patch grafts.

In comparison to conventionally used nonwoven, gel, foam, and foil constructions, embroidered implants offer some advantages:

- Improved mechanical stability
- Function and force flow appropriate construction
- Individual and local defined configuration – pore size, shaping etc. in terms of structure compatibility
- Selective material combination/scaffold constructions (absorbable, nonabsorbable fibers) [73.1].

Embroidered solutions for textile implant constructions offer comparable solutions to woven, braided, knitted or nonwoven materials with the advantage of an individual modification of the mechanical and structural properties by local variation of thread material and embroidered structure. So, embroidered constructions can be realized individually relaying the needed specifications [73.3, 21].

Since each implant causes a reaction with the tissue of the patient through the interface between implant and human tissues, the use of biocompatible materials in the embroidery thread technology is essential.

The base material e.g. nonwoven, which serves as a carrier of the embroidered structures, is composed of polyvinyl alcohol and is removed after the embroidery process. A cytotoxic effect caused by the base material must be excluded.

Figure 73.32 exemplifies an embroidered scaffold construction in a 10-layer construction with biocompatible yarns.

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