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SHORT COMMUNICATION

Holding donated human bodies in conservation: A novel interactive safe-keeping system meeting high ethical and safety standards

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ABSTRACT

"Mortui vivos docent". Learning from donated bodies is widely considered a corner stone in pre-clinical education, advanced clinical training, and scientific progress in medicine. Making such use of dead human bodies must, of course, accord with high ethical standards and legal constraints. Piety and respect towards donors require using their remains (i) for valuable purposes, (ii) with what we call 'practical decency', (iii) in an efficient way, and (iv) with the utmost safety for all parties involved. With regard to these goals, practical aspects of preservation, safekeeping procedures (for up to several years), and complete documentation become of great importance, but have so far only been realized unsatisfactorily.

Here, we describe the new *Safe-Keeping System-Münster* (*SKS-Münster*) that has been developed and implemented in the Anatomy Department of the University of Münster. Integrated components of the system include a paternoster transport system, a removal station with ventilation and an air barrier, RFID transponder technology, and an easy to use software package allowing the system together to provide all required functions in an unprecedented way.

1. Introduction

Hands-on dissection experience using dead human bodies has long been regarded as important and obligatory for teaching gross anatomy to pre-clinical medical students. Thus, dissection courses over a period of weeks during the first or second year of medical school have been the world-wide standard and are still practiced in most institutions, although these courses have come under scrutiny and are discussed controversially (Lippert, 2012). Given the era of online-learning, computer animation, and 3D-printing, experts from various fields have suggested and tested substituting (part of) gross dissection classes (Peuker et al., 1998; Sbayeh et al., 2016; Turney, 2007). Others fiercely defend the traditional practice (Rehkamper, 2016). From both perspectives, small step visual, manual, and haptic experiences are irreplaceably important. Moreover, some view dissection as a unique professional and psychosocial experience: realizing medicine's links to death, dying, and corpse donation (Gamlin et al., 2017) as well as providing a first contact with a real, albeit deceased person, on whom students are allowed to do medical work. Arguably, such early real interaction and experience with a "patient" can neither be replaced by imaging techniques nor by virtual media. On the other side, critiques consider both kinds of allegedly specific benefits as massively exaggerated and as more than outweighed by the supreme costs and efforts required to facilitate corpse dissection for legions of medical students. Finally, this complex dispute between traditionalists and reformists will have to be solved on an empirical basis and might well pave the further path to *reduced* dissection requirements combined with additional digital tools for anatomic learning (Balta et al., 2015; Losco et al., 2017; Vaccarezza, 2018; Wilson et al., 2018). In any case, dissection classes of some sort and to some extent are likely to remain a part of medical education, thus requiring safe-

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keeping of donated bodies according to the best possible standards of respect, efficiency, and safety.

The same is true for the safekeeping of corpses and human remains for *advanced* medical education and research. Unquestionably, yet-inexperienced physicians (and their future patients) can benefit greatly from training invasive procedures, such as endoscopy, or complex operative techniques, like spinal surgery, on the dead. Medical specialty trainees can profit from practicing rare invasive or new surgical techniques on human corpses. Finally, medical research can make beneficial use of dead human bodies or their parts in many contexts. Thus, teaching hospitals install *Post Mortem Learning Centers* in various forms to store, facilitate, coordinate, and integrate such activities (Losco et al., 2017; Püschel, 2009; Vaccarezza, 2018; Wilson et al., 2018). Again, in many cases this requires long-term safekeeping using chemical embalming or freezing of such remains according to the best possible standards of respect, efficiency, and safety.

Before we come to the more technical aspects of this task, a last word to the provenance of donated corpses as they are used in Germany and many (but not all) other countries (Habicht et al., 2018). Nowadays, potential body donors usually approach anatomical institutes and set up a legacy with the details of the procedure. In order to be accepted as a body donor, age limits are usually set and vary by institution (e.g. >50 years at the University of Münster; >18 years at Harvard Medical School). The legacy specifies the use of the body and/or body parts as well as the length of stay in the institution. Commonly, an institute's custody for the corpse ends after three years, while other donors want to provide their body or parts of it indefinitely. Contrary to false public opinion, most body donors, at least in today's affluent countries like Germany, do not donate primarily for financial reasons (i.e. saving funeral expenses), but from some altruistic or other idealistic motivation. Either they want to support medical practice and research, or they want to spare their next of kin post mortem troubles. Funeral costs are not infrequently shared with the donors themselves, given that anatomical institutes must often cover these expenses under tough financial constraints (Doll, 2017).

Members of the benefitting institution as well as all involved scientists, physicians, and medical students bear an (implicit) responsibility for handling donated bodies and their parts respectfully and carefully. After dissection classes are finished, a decent memorial celebration has become one institutionalized expression of gratitude to the deceased donors in many universities. But before this closure has been reached, high quality safekeeping becomes one important daily task – owed not at least to the donors themselves. In this context, it can be presumed that donors (and their relatives) want their bodies to be handled and transported in a gentle and dignified way, without confusing their identities, and to be put to the best use by those who ultimately benefit from their donations. We call this overall mode of contact with donated bodies 'practical decency'.

With regard to this aspect, there is room for improvement in the safekeeping systems, although the university facilities take great care to ensure that donated bodies are handled as carefully as possible, taking into account all ethical aspects. Systems currently in use generally consist, for example, of several storage locations, which require an equal number of expensive "airflow systems" and the same number of "lifting systems". In addition, a mobile documentation system with appropriate capacity is required, if available. The numerous storage, airflow and lifting systems are maintenance-intensive due to their number and may also require physical effort to relocate body donations. In many cases, when using formaldehyde, a protective mask might be required with the current system, an equipment which not only makes the handling of donated bodies more difficult but also less safe, since the mask limits the visual field and condensation can occur.

2. Results

2.1. Safety issues

For the purpose of long-term safekeeping, donated bodies have to be chemically embalmed, or alternatively are cooled down to −20 °C, which might be particularly advantageous for special training courses such as those on minimally invasive techniques, or particular orthopedic, emergency or hand surgeries. Persons who are known to suffer from a productive infection should be avoided as body donors for freeze conservation. Examples are the infections with human immunodeficiency virus or hepatitis viruses. While chemical embalming usually also leads to inactivation of pathogens, freeze conservation and thawing requires special precautions during handling, which in principle are similar to those applied in human surgery. In any case, people working on donated bodies should receive a safety briefing on the dangers of both chemical and potential infection risks. The main substance that has been used for chemical embalming for more than hundred years is formaldehyde (FA) which has, however, recently been classified as carcinogenic in very high concentrations. In mice and rats FA concentrations above 6 ppm (6 ml/m^3) cause naso-pharyngeal carcinomas (Greim, 2000) while FA exposure in humans has been classified as potentially carcinogenic (EU Guideline 67/548/EWG, Category 3) (Euler et al., 2009), but needs to be further evaluated (d'Ettorre et al., 2017). However, a very restrictive threshold limit value of 0.3 ppm FA has been established in Germany (Euler et al., 2009). Several attempts were undertaken to completely substitute FA, for example by ethanol (40%) but at least 2% FA seems to be still required. So far, the search for a safer complete substitute has not been successful (Balta et al., 2015), but current regulations und guidelines require highly reduced FA concentrations, air cleaning systems, and strict documentation of FA usage (Waschke et al., 2018). Specially designed workplaces and advanced storage systems are therefore urgently needed to meet the specific requirements for corpse safekeeping. An additional challenge is posed by the requirement of many iterated handlings of the bodies in question. For use in anatomical dissection courses and other iterated contexts, corpses have to be taken out and be re-stored repeatedly. Therefore, the system should be equipped with a lifting device in order to avoid heavy physical exertion for the employees.

Coming to more technical details now, the majority of working and safekeeping systems that are currently commercially available use high capacity top-down airflow. Taking in and exhausting FA-contaminated air at the bottom of the system, this top-down airflow needs to be as laminar as possible to prevent safety-decreasing turbulence in the FA-containing air. As a consequence, these safekeeping systems require a large amount of space, are difficult to clean, and often ensure the required occupational safety only insufficiently despite a large number of different ventilation systems with high technical complexity. It should also be noted that the risk of errors in donor identification and tracking during safekeeping and retrieval is increased if numerous separate safekeeping units exist.

2.2. Requirements, design, and implementation

In 2009, the Medical Faculty of the University of Münster decided to build a new education and diagnostic center, which should host the institutes of pathology, anatomy, and neuropathology under one roof. One of its functions would have to be the centralized high capacity safekeeping of donated bodies for students' anatomical education (about 420 students per year) as well as of corpses and body parts for advanced training courses and research purposes (see above). The needed safekeeping system was meant to meet the above described standards of decent, efficient,

Table 1
System requirements.

'Practical Decency'	Safety requirements for employees	Documentation and administration
• Easy handling • Gentle and dignified handling • Time-efficient handling • Decent looking system	• Closed Safe-Keeping containers with light barrier sensors • Hygienic handling • Avoidance of chemical toxicity • Minimal physical effort	• Encryption of donor data • Clarity • Ease of use • Unambiguity

and safe handling, should allow for optimized documentation and administration of the stored bodies or body parts and their utilization, and had to fit within the limited available space. In February 2011, we began designing, building and implementing a safekeeping system that would meet all of these requirements (Table 1). Despite considerable challenges in developmental regards we managed to implement our system, which has now been running for more than six years, and we consider it highly recommendable.

2.3. System construction

The concept is based on a modular construction, consisting of a horizontally and vertically circulating endless paternoster system, which carries and transports half gimbaled U-shaped steel-gondolas, each carrying two safekeeping containers (SKC) for the donated bodies. The removal station(s) is/are equipped with an air barrier that protects employees from chemical stress and a lifting system that allows the corpses to be handled without physical exertion and the SKC to be removed for cleaning. The entire system is computer-assisted, and is equipped with an easy to handle software package that was newly designed and implemented so as to manage the entire system's operation, documentation and administration. The modules of the system can be adapted to various capacity needs, including the installation of one, two or even several removal stations, allowing adaptation to different requirements. The principal setup as implemented in the Anatomy of the University of Münster is illustrated and documented in Fig. 1, and thus the system was named *Safe-Keeping System Münster* (SKS-Münster).

2.3.1. The paternoster system

The paternoster setup is built into a box-shaped steel-frame (about 13 m × 7 m × 4.5 m) made of double-T beams, which in turn is placed on a concrete slab. Ten steel gears are placed, five on each side, of the long steel frame sides to divert the direction of two endless chains (one on each side), so that a total of four vertically stacked floors arise (Fig. 1). Our system carries forty U-shaped steel-gondolas mounted on rollers, which are half-gimbaled running on the corresponding height-arranged four stainless steel rails that are placed on the four levels of the steel frame. In our system, each of the gondolas carries two SKCs, the size of which can be varied according to requirements. Electrical motors drive the paternoster endless chains and allow movement forward and backwards, and the program ensures that the shortest routes are chosen to reach the removal station automatically. Thus, even the furthest gondola takes only about five minutes to reach the removal station, enabling fast handling. The entire system is housed in a locked room with continuous air exchange. For safety reasons, the access doors are electrically locked while the paternoster is running. Two transparent PMMA safety glass panels are mounted at the front of the removal stations and can only be opened for safekeeping or retrieval under resting conditions. Conversely, open safety glass panels or open doors block the system from rotating, preventing accidents during operation. In addition, three laser-light barriers monitor the sealing of each of the SKCs. In this way a safe system operation is guaranteed. For trouble free running, annual maintenance and inspection of the mechanics is sufficient, greasing of all bearings a check of the container transport-chain. Special safety precautions, e.g. masks, are not necessary for the technicians during maintenance work, as the containers are gas-tight and the room is well ventilated.

2.3.2. The removal station

The removal station is located at the front side of the system (Fig. 1). To meet our specific needs, we arranged a *double* removal station with a ventilation barrier system (laminar flow) that works on the three-zone principle. It includes the hood area, integrating clean air nozzles, which produce a stable separating clean laminar air curtain with ejector effect (barrier veil) between the SKCs and its users. Materials released in the working area are drawn in and transported to pollutant extraction, protecting users from product emissions. The stable barrier veil (0.20 m/s to 0.50 m/s) creates a robust retention capacity so that the FA content is not exceeded (measured below detection limit), which is in accordance with the guidelines of the Committee for Hazardous Substances ("Ausschuss für Gefahrstoffe") in Germany. Furthermore, after the *SKS-Münster* had been running smoothly for more than six years, FA-load measurements were carried out again using FA "Dräger-tubes" and were again found to be below detection limits in front of the removal station where employees work. In contrast, nearly 2 ppm were detected when measured directly above the opened SKC that was filled with a fixing solution that contains about 2% FA. A hydraulic lifting system installed under the ventilation barrier allows safekeeping and removal of the donors without physical effort for the employees (Fig. 1). An additional anteroom with high air exchange is connected to the removal station. For intermediate storage of donated bodies, a ventilated extraction system is installed in this room as well, which also serves to clean the containers. The use of protective masks when handling bodies or containers is not necessary. The control and positioning of the SKC at the removal station is ensured by a newly developed, programmed and programmable software, named *SKS-Software*.

2.3.3. Software functions, maintenance, and system handling

The software developed and implemented for the *SKS-Münster* uses the freely available software package "Access" running on standard computers. The program is designed for all necessary documentation and administration tasks with regard to body donations and also controls all paternoster mechanical processes (Fig. 2).

2.3.4. Documentation, archiving and administration

(Fig. 2, left and middle column). The program includes a complete dated documentation and archiving (database) of the body donations, of body parts, the use-specific manipulations and the final fate. Each donor has an individually logged documentation sheet, which includes the encrypted body donors' identities. Importantly, we use RFID (Radio-frequency identification) transponder technology to unambiguously tag any bodies or body parts, which currently allows an interactive tracking and identification. Contract agreements (time limits of donation), treatments and interventions of donations can also be recorded and tracked. The program is also well suited for planning courses such as gross anatomy, advanced medical training or research programs. For those purposes, subroutines can be easily generated, which move the gondolas in the required order to the removal station. This function is of

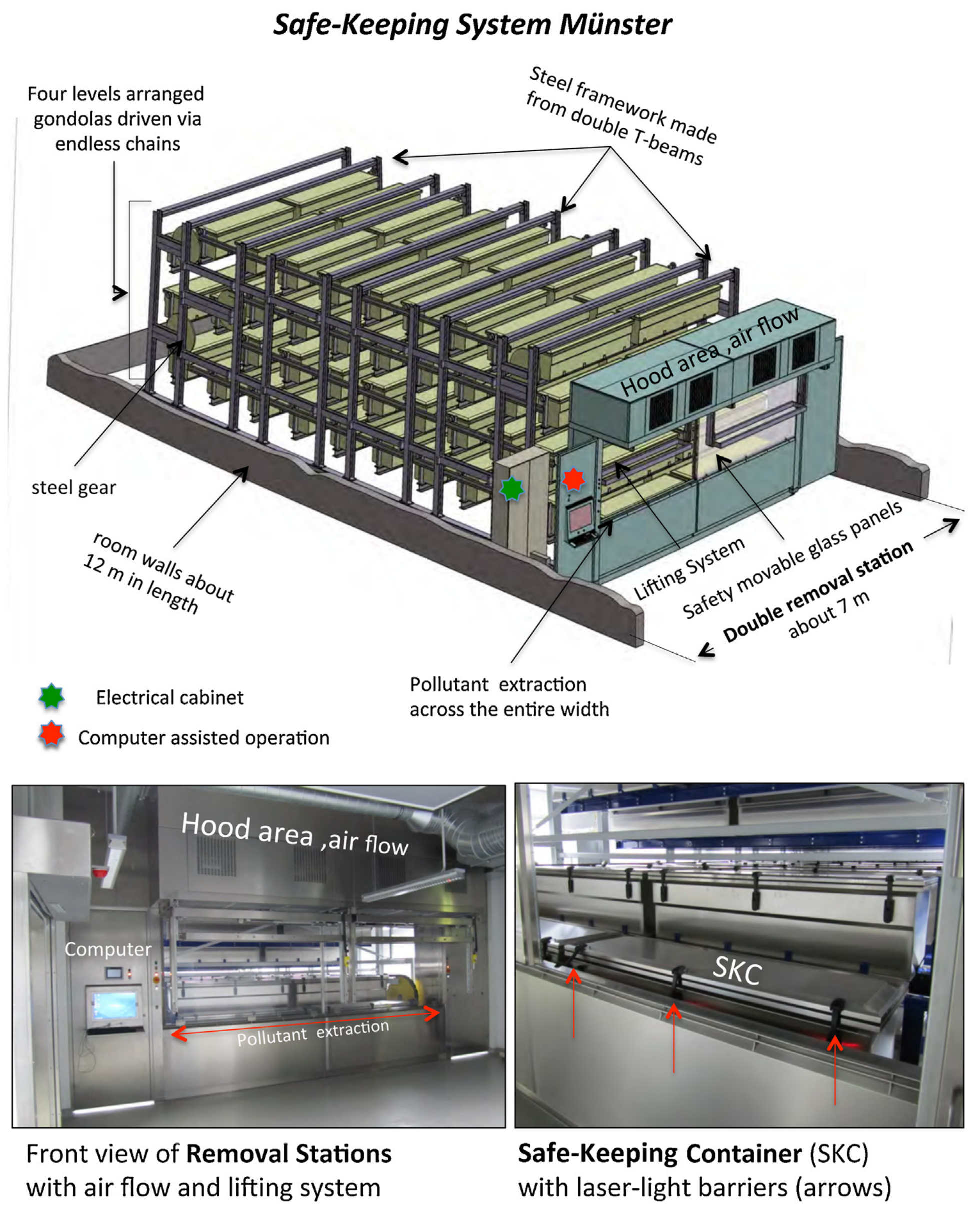

Fig. 1. Illustration of the basic construction of the SKS-Münster, consisting of paternoster transport system, double removal stations, air flow and software on a standard PC. Lower left panel: Front view of the removal station of the SKS system with the safety front screens, the air barrier and the computer unit. Lower right panel: Cropped picture of the removal station, showing a closed SKC. The arrows (red) point to the light barrier used to secure the SKC closure. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

great advantage for fast and effective safekeeping and retrieval. An example of the program interface is shown (Figure S1). There are capacities in the program also to document and administer other types of conservation such as freezing. The safekeeping of these donations, of course, is outside the scope of *SKS-Münster*.

2.3.5. Mechanical control

(Fig. 2, right column). The computer-aided control of the mechanics includes important safety controls during operation such as the electronic closure-control of the SKC, safety glass panels and doors. Conversely, all mechanical processes during transfer to and from the SKC will be blocked electronically as well. The program also allows automatic sequential positioning (queues) of the containers to the unloading stations for safekeeping or retrieval, which is very useful e.g. for planning any type of teaching courses. Finally, the program is designed to be flexible allowing adaptation to different user-specific demands.

2.3.6. System operation requirements

For employees who are to operate the system, training is required as usual for new systems. This applies to both the software and the handling of the computer-aided mechanics. In particular, appropriate safety devices such as light barriers and magnetic switches are provided for ongoing operation, so that accidents are practically ruled out. The safety standards correspond to the standards for mechanical engineering. The control and administration software is largely self-explanatory, so that no unusually complex training of the system with regard to mechanical safety and handling of the software is required.

3. Limitations, conclusions, and discussion

Learning from donated dead bodies will certainly stay with medical education and research, even under changing conditions regarding the extent of hands-on dissection courses for pre-clinical

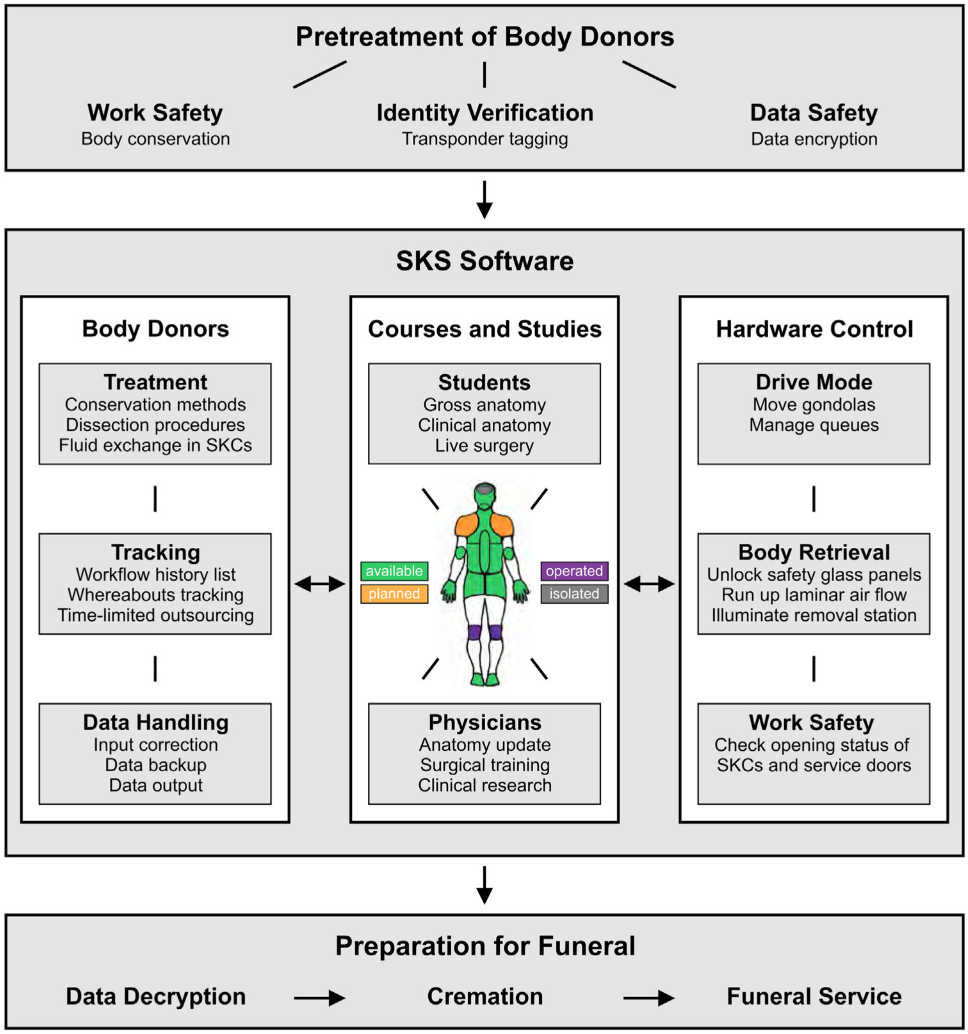

Fig. 2. The illustration depicts the scope of the SKS software, which was developed and implemented for the SKS-Münster. This includes the documentation and administration of the body donors, the planning and execution of courses as well as the control of the mechanics as indicated.

students. Storing and handling these bodies with 'practical decency' (including safety and efficiency) is an important issue – owed not at least to the deceased donors themselves. By designing a safe and efficient safekeeping system, we have made a contribution to establishing this goal.

Highest advantages of the described system include space-saving storage (Paternoster principle), only one removal front with one air flow protection for storage and retrieval (removal stations), where the later one can be performed without physical effort and without need for masks or similar safety devices. The RFID technology helps to protect the employees from mistakes and avoids mix-ups. The software includes the control and the complete documentation as well as course-planning. Since all maintenance and documentation work is performed at one location, this results in considerable timesaving effects compared to traditional systems using multiple storage places. Moreover, mechanics are easily accessible for the maintenance technician.

Another point of discussion is the use of potentially explosive fixing solutions (e.g. ethanol) in the system. Some colleagues prefer this type of preservation as the formaldehyde concentration can be reduced. Whether the system can be used for high ethanol concentrations where explosion protection is absolutely mandatory would have to be tested. Since our institute uses a formaldehyde-based fixation solution, there was no need to establish the SKS-Münster with explosion proof techniques.

Together, the entire system, including the mechanics and the software, is robustly designed and implemented as documented by a 6 years of trouble-free run while annual maintenance was carried out. The modular design allows adaptation to the specific capacities and applications required. However, there is still room for improvements regarding mechanical details and the documentation. At present, the placement and retrieval of body donations and body parts is interactive. Although RFID transponder technology is not necessarily required, it is a big advantage to protect the operating staff from mistakes and it also helps to avoid mix-ups. In addition, a suitable further development would be an automated recording system with RFID transponder technology during storage and removal of bodies or body parts.

Author contributions

H.S. developed the idea and designed the overall concept for the development of the SKS-Münster, including the modular structure consisting of paternoster system, removal station and software for every form of administration, handling and control of the mechanics, and accompanied the implementation in close cooperation with the manufacturers. H.S. and B.SS. wrote the manuscript, and B.S.S. gave the intellectual input to ethical questions of the entire system. U.O. F.W. coordinated and supervised all construction details and implementations. S.W. und W.K. contributed to the design

and implementation of the program and contributed further with fruitful discussions. S.T. wrote the grants and supervised and coordinated the entire implementation process.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.aanat.2019.05.007.

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