Project report:

Development of a new infusion stand for clinical practice: Cart Around Care System (short title: CArCaSy)

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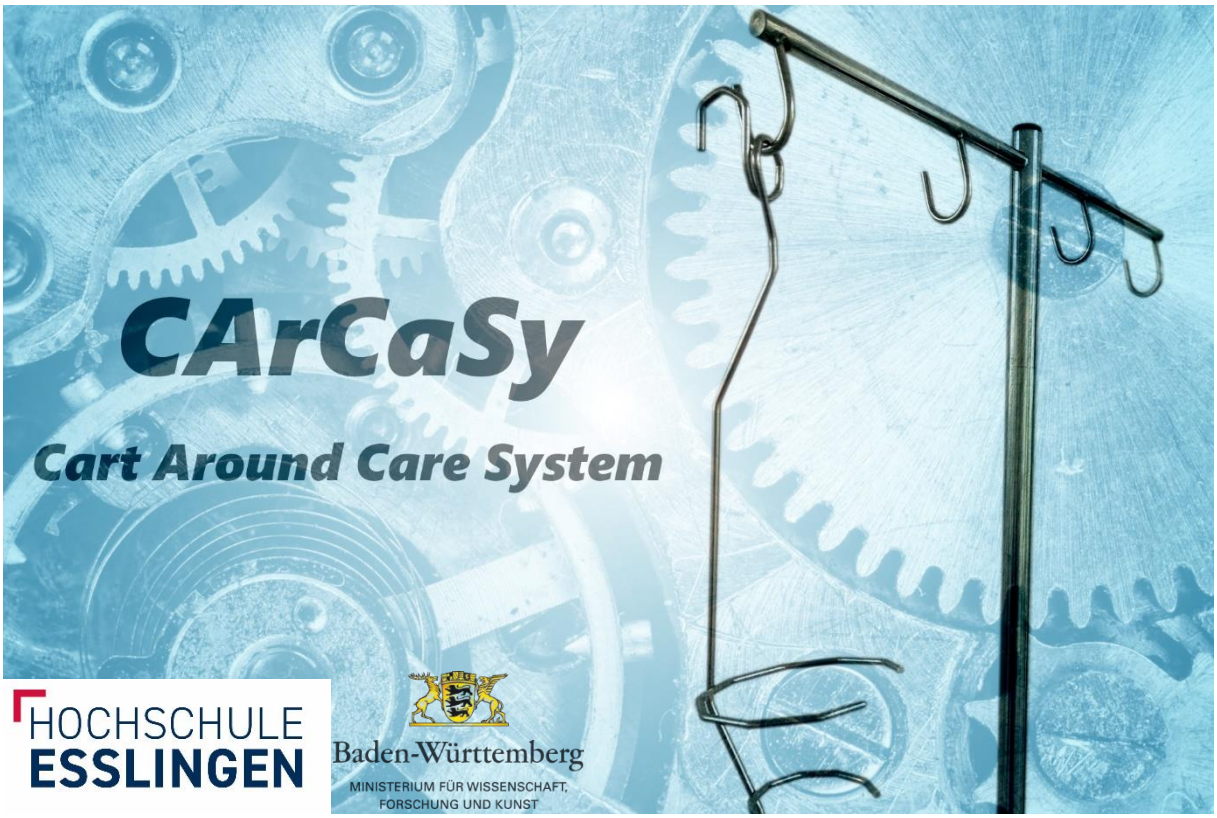

Contact:

Prof. Dr. rer. cur. Astrid Elsbernd – Social Work, Education and Nursing Sciences
E-Mail: astrid.elsbernd@hs-esslingen.de

Prof. Dr.-Ing. Franziska Meinecke – Mechanical and Systems Engineering
E-Mail: franziska.meinecke@hs-esslingen.de

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1 Abstract

Infusion stands are a central tool in health care. They are mainly found in hospitals, are usually in use for many years, sometimes carry enormous loads (e.g. irrigation solutions, perfusors), are also used by mobility-impaired persons to support walking, promote mobility and self-determination during ongoing infusion therapy, and must be stored in sufficient numbers. The weaknesses of the existing design of infusion stands are well known to users. Nevertheless, for decades there has been no further development or adaptation to new, changed requirements, let alone to new technical possibilities. In the short term, it makes sense to further develop the existing infusion stand models in an evolutionary manner in order to quickly produce an improvement in the functions and to mitigate the greatest weaknesses. In this respect, the project team has shown in the context of technical developments that there are very simple, but in terms of functionality, safety and data protection very worthwhile adaptations that can and should be taken up by the industry. The redesign of the basic element alone brings so much improvement for the use of this aid that an industrialization in several senses – for the individual and society – would be more than promising. With this research project, the project group would like to give an impulse for the participatory involvement of users in assistive technology research. The user groups can participate in different phases of the product development; at least the products should be evaluated regularly in their application by the users.

2 Detailed description of the project results and achievements of the first work package (responsibility Prof. Elsbernd)

2.1 M 1.1: Kick-Off-Meeting

The beginning of the first work package and thus the start of the project was in the "breathing space" of the COVID-19 pandemic between two waves of disease, i.e., spring and fall 2020. For this reason, the project team was initially able to hold smaller face-to-face meetings and lay the organizational and methodological foundations while adhering to hygiene guidelines. Due to the increased caseload in the fall of 2020 and the need to reduce face-to-face contacts, the project team now worked from home. Meetings and conferences could be held via video telephony or by telephone.

As part of the foundation of the project organization, it was realized at the start that an adjustment of the work packages in work step phase I. was necessary due to the current situation. Accessibility to our project partners in terms of kick-off events and a direct requirements survey was difficult or impossible. An advantage for the project resulted from a

student project group of the Bachelor study course Nursing/Nursing Management of the University of Applied Sciences Esslingen under the direction of Prof. Dr. Elsbernd working thematically at the same time. Due to the criterion of a completed education in the field of nursing or/and obstetrics as a study entrance qualification and the common simultaneous professional activities of the students in the different practical fields, these students functioned as stakeholders (users). Within the framework of the curricularly anchored project work, the group developed its list of requirements on the basis of a rich expertise, problem formulation from literature as well as suggestions from internal project meetings and discussions in the interdisciplinary plenum. A systematic foundation of the identified requirements and problems was not achieved, not least because of the small number of publications.

At the same time, in the first phase of the project a systematic review was carried out, the entire relevant literature on the subject of infusion stands was examined and a product overview of nationally and internationally common infusion stand types was compiled. The results were discussed and evaluated by the research team and an initial list of requirements was drawn up.

Further joint project and sub-sessions of the students from Mechanical Engineering and Nursing with the scientific staff of the CArCaSy project resulted in a close exchange and developed positive synergies such as joint utilization analyses of individual product increments. Within the interdisciplinary exchange, subject-specific peculiarities in communication became apparent. One experience, for example, was that formulations of requirements such as "The rollers must be smooth-running" did not provide clarity on the engineering side: "How many Newton meters?" So there was already a need for consensus and translation within the formulation of questions to the users or in the formulation of requirements to the developers. Further consideration was given to how everyday problems in dealing with the infusion stand could be translated and communicated to the technology development team. Approaches here were, in addition to discourse, the use of short video sequences on application problems such as loud wheel noises or the formulation of practical scenarios. It was precisely these different usage scenarios that were able to clearly illustrate the heterogeneity of the users of infusion stands and the resulting need for modularity - for product individualization.

Procurement of materials

To illustrate the topic, infusion stands were needed right at the beginning of the project, the procurement of which turned out to be more complicated than assumed at first. The attempt to use local medical supply companies as a source for infusion stands failed due to the fact

that none of these companies had them in stock. This could support the thesis that infusion stands play a rather minor role as aids in the home setting and that the main setting can be seen in acute hospital care or inpatient long-term care. The first attempt to place an order online failed because of the logistics of the aid distributor. Thus, it was not until three months after the start of the project that the mechanical engineering department was able to inspect two free samples from the company Provita Infusion stands.

In addition, further international infusion stand models were to be purchased. Here, contradictory aspects emerged in contact with the companies: On the one hand, we met with direct rejection on the grounds that sales were only possible to health centers, i.e. not to universities for research purposes. On the other hand, however, we also encountered a great willingness to provide models - with the request to exchange information. The acquisition of applications (e.g. infusomatics) is equally necessary for a comprehensive presentation of product requirements. Discarded infusers and perfusers can be obtained as "dummies" for weight ratios. The company B. Braun supported the project with a SpaceStation for the representation of the required space ratios of the newer perfuser generation.

2.2 M 1.2: Ethical clearing

The ethical clearing was submitted to the Ethics Committee of the Medical Faculty of the University of Tübingen and accepted as unconsidered in November 2020. The content of the ethics application consists of project introduction, project flow chart, study information, consent forms, informed consent forms and data protection information.

2.3 M 1.3: Requirements list 1

Systematic literature research

In the first phase of the project, a systematic literature search on the subject of infusion stands was conducted in the databases Pubmed, Cochrane Library, Cinahl and Meditec using the search terms "infusion", "iv", "intravenous" and "drip" - combined with the terms "stand" and "pole". In the case of hit results, the terms "design", "product design", "development" and "product development" were also included in the search mask. In Pubmed, the terms "iv stand", "drip stand", "iv pole" and "intravenous pole" yielded 36 hits. Of these, 14 hits were relevant (3 pediatrics, 2 kinesthetics, 3 intelligent systems and robotics, and 6 design-related).

Within the Cochrane Library, the terms "iv stand," "iv pole," and "intravenous pole" yielded 10 hits, but these did not address the infusion stand. Cinahl produced 30 hits with "infusion stand, "iv stand," "drip stand," "iv pole," and "intravenous pole," while Meditec, as a medical technology database, returned one journal article from 1984 on the search term "infusion stand." In addition, the search terms "infusion devices" alone and in combination with "design", "product design", "development", and "product development" were queried in the above-mentioned databases due to the clear results. Hits on this mainly dealt with infusion systems and infusion pumps - but not infusion stands. In the German-language nursing databases, Carelit was queried with the terms "infusion", "infusion technology" and "infusion stand": The only hit found here that dealt with the infusion stand was a preliminary article by the project initiators Meinecke and Elsbernd. In addition, snowball searches were conducted on common platforms such as Google, YouTube, and Pinterest.

In summary, the literature can be summarized in the focal points "design developments", "interaction infusion stand/user" and "comparative studies", which are mostly a combination of both.

Construction and design developments

- Use of robotics (Ghandour et al., 2016; Hajj-Moussa et al., 2018; Sayed-Kassem et al., 2020)
- Design of an infusion stand that slides on the bed (Kordae & Srinivasan, 2013)
- Design of an infusion stand for conventional use and as a ceiling suspension for Chinese hospitals (Vignali, 2006)
- Communication "add-ons" such as the Korean "Talking Pole" designed to provide adequate information to patients in the emergency room (Yoo et al., 2018)
- Design of the infusion stand "Sprout-IV Pole" which focuses primarily on children (Parbhu et al., 2019)

Infusion stand – user interaction

- Study of movement and directional changes with the infusion stand (Hachigasaki, 2020)

- Comparative study of upper extremity and muscle loading when using a common infusion stand versus a newly designed infusion stand (Notion Medical IV Crane™) (Forman et al., 2018)
- Comparative study of mobilization of postoperative thoracic surgery patients using a common infusion stand versus a newly designed "intravenous pole/walker (IVPW)" with the ability to attach multiple devices to it (Nesbitt et al., 2012)

This systematic literature search can only confirm the paucity of available literature on the IV pole (Elsbernd et al., 2019) within databases. Although the Japanese study on movement and direction changes with the infusion stand (Hachigasaki, 2020) adds a nursing scientific study, compared to the mentioned omnipresence of the product in everyday nursing practice (Elsbernd et al., 2019), this is – from a strictly quantitative point of view – not sufficient. The low proportion of nursing or health sciences in direct product development is particularly critical. If nursing or health scientists are involved, this happens increasingly in the phases of product evaluation.

When sifting through the international product range of infusion stands, it very quickly becomes clear that it is necessary to research outside of databases. In popular search engines such as Google, but also on platforms such as YouTube or Pinterest, a variety of product variants can be identified. Examples of this are experimental models such as the Japanese "EZ Pole", which replaces the infusion stand with a shoulder holder, or the "Tarsus Violetta" from Sweden, which folds up like an umbrella. In the field of normative literature, patents in particular are stored in the search engines. Likewise, the majority of innovations and model variants can be found in the respective product catalogs of the assistive device manufacturers. However, research on this leads to the conclusion that most product "innovations" are variants of already existing solutions and these are usually developed very closely to the previously used product. Furthermore, the lack of research and development reports on these models within scientific databases prevents a possible linking of follow-up projects. The process of product analysis and the identification of user needs cannot be scientifically traced here. This shows why product development away from commercial production is necessary.

In her master thesis "Valuing the voice of children" Parbhu (2015) shows a transparent product development process. While the focus of this work is on the design of a product conceived for children, it is one of the few works that allows insight into the development and evaluation of an infusion stand. Parbhu et al. (2019) compare the design of a conventional IV pole and the "Sprout-IV pole" developed by Parbhu in the study "Differing Perspectives: Evaluation Of a New IV Pole by Children and Adults." 32 children between the ages of five and 18 as well as adults (45 legal guardians and 12 registered nurses) compared two infusion stand variants under the aspects of "mobility, safety, aesthetics and functionality". Mobility is assessed via the three items "The stand was easy to move", "The stand went through doorways and sanitary facilities" and "The stand could be moved quietly". Safety is evaluated via the items "The stand was stable," "The stand was sturdy," and "The stand is safe for children to use." Aesthetics is asked about "I like the look of the stand". Functionality is assessed via the statements "Children liked using the stand," "Children could move the stand," and "Children used the stand in ways that were not intended." In addition, caregivers are asked to rate functionality with the items "Pumps are easy to attach," "Infusion bags and bottles are easy to hang," and "The stand was easy to store when not in use." In comparison, Parbhu et al. found that among all respondents, safety was perceived as the most important, followed by mobility and functionality, while aesthetics was perceived as the least important.

Generating requirements list 1

The generating of the first list of requirements can be understood as a merger of the findings of the student project group and those of the research team. Parbhu's findings and division into the needs categories of safety, mobility, functionality and aesthetics (2015) serve as the theoretical basis for the requirements. For the generating of our list of requirements, we made adjustments regarding the division. The reason for this is the realization that the common infusion stand is divided in the literature according to its structure into the three main parts "lower part (or base)", "middle part" and "upper part (or suspension)". This structure has also been established in this project and has been adopted, which may also result from the necessary smallness for technical solutions. In the development and elaboration of this division, the limits of this systemic approach became apparent, which is why "general requirements" and "special requirements for individual components" were formulated. This discrepancy between the desire for a clear analytical division and reality is reflected in Parbhu's

"Safety" category. It is found as the main topic "G3 Safety" within the general requirement, but at the same time can be derived from the majority of the other subtopics.

The prioritization of the individual requirements is based on the ICN Code of Ethics for Nurses and the professional understanding stated therein: "Nursing care is respectful and unrestricted with regard to the characteristics of age, skin color, culture, cultural affiliation, disability or illness, gender, sexual orientation, nationality, politics, language, ethnic affiliation, religious or spiritual beliefs, legal, economic or social status" (International Council of Nurses, 2021, p. 4). Fundamental values here represent autonomy, justice, equality, and safety. These values are reflected in the various main topics and sub-topics, for example in the desire for non-discriminatory design or resource-saving materials. Prioritization takes place exclusively within the individual main topics (example: G3.1 high prioritization - G3.5 lower prioritization). In contrast to Parbhu, the prioritization of the general requirements is chosen arbitrarily and does not represent a ranking, or this ranking results in the special requirements according to the product structure from bottom to top.

General requirements

G1 Data protection

G1.1 For outsiders, the type of infusion therapy (especially drug name) and the draining systems (e.g., drains) are not recognizable.

G1.2 Data that can be linked to patients are not collected (e.g. GPS).

G2 Hygiene and environment

G2.1 The material of the individual components can be disinfected and easily cleaned.

G2.2 The surfaces are not damaged by common disinfectants and cleaning agents.

G2.3 The individual components have been developed in a resource-saving manner and are recyclable in the sense of a sustainable product cycle.

G3 Safety

G3.1 The infusion stand is tip-proof.

G3.2 The infusion stand stands securely and immovably when the brake is tightened.

G3.3 The parking brake is operated and released centrally. The brake can also be operated with low grip strength and fine motor skills.

G3.4 The infusion stand gives a safe feeling due to its stable construction.

G3.5 The possibility of personalization is available. This prevents patient or medication mix-ups.

G4 Economic efficiency

G4.1 The infusion stand and its modular parts must be space-saving and efficiently storable.

G4.2 Individual parts of the infusion stand must be easily replaceable in the event of a defect.

G5 Design

G5.1 The end product can be operated by people regardless of body size or physical strength.

G5.2 The chosen design of the infusion stand can be used intuitively and self-explanatory by every user.

G5.3 The infusion stand promotes or ensures the self-determination of the user.

G5.4 The infusion stand is electrified and must be charged automatically during storage.

G5.5 Electronic devices such as infusion pumps, perfusers or electronic drainage systems can be charged centrally from a power source in the room and warehouse.

Special requirements of individual components

S1 Bottom part

S1.1 The base of the infusion stand is designed to allow physiological/safe gait. This means that the step length can be freely selected and the user's gaze is detached from the base of the infusion stand.

S1.2 The wheels of the infusion stand are non-slip even when wet on the different floor structures, such as various plastic floors and tiles.

S1.3 Unrestricted mobility of the infusion stand in all directional axes is possible in a confined space.

S1.4 The wheels of the infusion stand easily overcome obstacles such as thresholds and elevator edges without much effort.

S1.5 The wheel tread noise is quiet on the different floor structures.

S1.6 The wheels of the infusion stand are without grooves and crevices where dirt etc. gets stuck.

S1.7 The infusion stand independently maintains the track/line of travel.

S1.8 The wheels and base clean themselves by brushing on the charging station.

S1.9 The base has an underbody light, making it easier to walk in dark rooms.

S2 Middle part

S2.1 The infusion stand is easily height-adjustable for gravity infusions without effort.

S2.2 Drainage systems such as urine bags are easy to attach.

S2.3 Infusion pumps and perfusers can be securely attached at working height and do not obscure the view when pushing the stand.

S2.4 There are storage areas for carrying smaller items and drinks.

S2.5 Optionally, heavy items such as oxygen cylinders can be securely attached.

S2.6 A 12-volt USB socket is installed for charging smartphones and the like.

S3 Top part

S3.1 The infusion stand includes a built-in holder option for glass bottles (volumes 50 ml to 500 ml).

S3.2 The holding devices are designed in such a manner that up to four bottles and infusion bags can hang from them at the same time.

S3.3 The muscular strain caused by overhead work is reduced. Injuries are thus prevented.

S3.4 Unneeded holding devices can be folded.

Prioritizations, user group and settings

On the whole it becomes obvious that the requirements identified reflect different interests in the use of the infusion stand. Furthermore, it is to be expected that requirements in the implementation are in direct or indirect conflict with each other and that the requirements must therefore also be prioritized in a certain way. Against this background, it makes sense to describe the main user groups and the usual fields of application.

User groups

The infusion stand is mainly used by patients/residents, nursing staff and physicians. The interests involved in its use can vary: nursing staff/doctors use the infusion stand to attach feeding systems (e.g. infusions/medications or irrigation) safely and in an ergonomically suitable work process (e.g. easily accessible by adjusting the height). In this process the infusion stand should ensure the correct/safe application of medications. The fact that infusion stands are easy to move is only of decisive importance for healthcare professionals when they roll the infusion stands out of the patients' rooms, for example to apply infusions or to deposit the infusion stands in a storage room after use. For patients, the focus is on supporting their own mobility: infusion stands enable them to move around the room, in the bathroom and outside the patient's room, despite the application of medication in the form of infusions - which can sometimes take several hours. This mobility is of great importance to the patients; the movement is usually beneficial to their health and enables them to keep busy. It can be regularly assumed that patients who move with an infusion stand can be quite different with regard to physical impairments. Some patients will be in poor physical condition and may lean on the infusion stand. Other patients may be unsteady overall and have more difficulty carrying the infusion stand. Still other patients may be cognitively impaired and overtaxed with the necessary coordination and motor skills when handling the rolling infusion stand. Overall, it can be assumed that this is a highly heterogeneous group of users (especially age, physical and mental condition, use of other aids).

The infusion stand is used most frequently in the hospital setting. There are few structural barriers here. In most cases, there are no or only a few steps to negotiate, but there are often small unevennesses at the elevator doors. Overall, the movement areas on the wards and especially in the patients' rooms and the associated wet cells are very busy, so that everyone has to move in a relatively confined space. This makes it particularly difficult to carry an infusion stand sideways; carrying an infusion stand in front of the body requires special care.

2.4 M 1.4: Requirements list adaption I

The aim of milestone M 1.4 was to adapt the list of requirements by collecting user requirements from the care sector.

Contacting the project group

At the beginning of the second project phase, the first contacts were made with the nursing staff participating in the project. The project participants were requested by the nursing management of the respective clinics and organized via a central contact person for the project. The project group consisted of nurses from the clinics of urology, gynecology, dermatology, ophthalmology, ENT, radiation oncology, internal medicine, general and visceral surgery, and pediatrics. Project meetings were arranged via doodle query and meetings were held online via Webex. However, due to nurses' shift patterns, not all members of the group were able to attend the meetings. For this reason, PowerPoint slides and content summaries were subsequently distributed to all project participants to achieve as consistent a project interim status as possible.

First meeting – kickoff event

The first kickoff event took place in mid-April 2021 with six participants, lasting 60 minutes. The aim was to get to know each other and to provide a theoretical introduction to the research project. Methodically, the input was processed and communicated via PowerPoint slides. The content focused on the project status, excerpts from the first list of requirements and the tasks of the participants in the project. Since the presentation slides had already been sent to the participants in advance, they took up a smaller part of the meeting. In the discussion that followed, it became apparent that many project members had already formulated fixed requirements regarding an infusion stand for themselves. For this reason, it was agreed with the group to meet for a second problem and requirements gathering meeting in the near future. The participants were asked to collect images and ideas in order to make the respective problems more comprehensible for the technology.

Secound meeting – Problem description from practice

In advance of the second meeting, one project participant took photos of the infusion stands currently in use and their modifications. Another participant collected product requirements in her work area and sent them to the project group. During the second meeting, five project participants from the fields of pediatrics and various internal medicine disciplines were gathered for an exchange. The group interview started with the question "What moves you about infusion stands? What bothers you and where do you see need for development?". This

was followed by a free and informal description and discussion of existing problems, product wishes and suggestions for product changes within the group. In preparation for the interview, the project team identified problem areas that were not yet sufficiently saturated. If this saturation did not result from the course of the conversation, these areas were specifically inquired about by the interviewers.

In the subsequent analysis, the recorded group interview was viewed again and statements made by the participants were recorded in tabular form. A transcription was only carried out for individual, particularly concise descriptions of problems or evaluations and included as a quotation in "Notes". In a second step, the participants' statements were assigned to the categories of the list of requirements (see Table 4). The area of G5 design was divided into the categories "Electronics" and "Mobility". In addition, "user description" was included as a description of patients. In total 54 statements were collected, analyzed and assigned to the following areas.

Users

The group describes patients in different oncological settings. The nurses focus on the long intravenous chemotherapies of 18 to 48 hours total duration, with the use of several extra-long infusion systems (three meters and more) and infusion machines. Mobility with the infusion pole is an issue especially in these settings. Since there are rarely interruptions in infusion therapy within chemotherapy schedules, patients must arrange all activities and routes with the infusion stand.

Economic efficiency

> *"We hope that we will never have to store all the infusion stands at once. Because we don't have the space" (Quote from a nurse, second project meeting).*

All descriptions regarding storage, models and work processes are assigned to the topic of economic efficiency. According to the interviewees, each department or ward has its own stock of infusion stands - models of different ages and makes, which are stored in one room. The assignment to a department is indicated by an adhesive label on the infusion stand,

although the nurses could not give an exact number of infusion stands available in each case. The infusion stands are stocked with the necessary solutions and infusion systems outside the patients' rooms and then pushed to the patients. One interviewee from the area of oncological pediatrics states that infusion stands for adults are used in her area. She sees one reason for this in the insufficient fastening options for infusion machines and perfusers on pediatric infusion stands.

> *"I can't say to the patient, 'Sorry, you're not allowed outside. You have the wrong infusion stand.'" (Quote from a nurse, second project meeting).*

When asked directly whether it would be conceivable to use different infusion stand models ("outdoor models" for longer distances and "indoor models" for going to the toilet, etc.), the group reacted with rejection. The respondents justify their rejection on the one hand with poor manageability (who is allowed to go where with which infusion stand model), and on the other hand with the efforts on the part of the hospitals to achieve uniform product equipment. Modular options in the sense of an exchangeable base/suspension or the use of "add-ons" for specialist requirements are viewed positively. The idea of "infusion stands permanently installed on beds" is evaluated negatively. The reason for this evaluation lies in the restriction of mobilization: If, for example, the infusion stand is mounted continuously on the right side, this precludes mobilization via the left side of the bed. In the field of pediatrics, the patient bed is understood as a protected area to which no medical products are attached.

Saftey

Descriptions regarding the safety of infusion stands are reported with a focus on the field of oncological paediatrics. In this field, intravenous access is mainly established via a large-lumen Hickman catheter (special, partially implanted venous catheter), which requires protection against disconnection due to its size and invasiveness. This protection is achieved by a pocket that is fixed on the patient's chest with the help of a tube clamp. Infusion therapies in paediatric areas are administered exclusively via infusion machines, so that gravity infusions do not play a role here.

The use of volume/drip/fill level alarms is not considered important, as these functions are taken over by infusion machines for correspondingly sensitive infusion therapies. Radio bells on infusion stands are rejected because they cannot be located, or it is pointed out that there is already a patient call in the rooms. One respondent expressed the wish for a lighting option at the base as "underfloor lighting" for going to the toilet at night and in the form of a small LED on the suspension, so that the infusion bottle level can be assessed during night duty without the use of torches.

Electronics

In addition to the usual infusions, mainly electronic devices such as infusion machines, perfusers or nutrition pumps are attached to infusion stands. The standard version of the infusion stand forces users to attach and operate the equipment below their respective working heights. The reason for this is the construction of the model, or the length ratio between the lower and upper bars. If the equipment is used on the upper (inner) bar, the centre of gravity of the infusion stand shifts upwards. Furthermore, the practical nurses report a "twisting against each other" of the two poles up to a tilting. Electricity is considered important in the surveyed areas and some disciplines already equip their standard infusion models with socket strips. The reason for this is the high use of infusion machines and perfusors, especially in oncology. An electrified infusion stand with a wireless charging option via charging station is only considered good to a limited extent by the nursing staff: A charging station on the floor would take up additional space and cause further problems (hygiene or high susceptibility to repair due to cleaning agents, etc.).

Mobility

A cordless infusion stand or the reduction to one mains plug is also an important issue in terms of mobility. One nurse commented: *"The fewer plugs that have to be unplugged, the better it is!"* Due to the often-pronounced physical weakness of patients in oncology, every additional power cable plugged in is therefore a potential obstacle to mobility.

Another problem area described is the height adjustability of the infusion stands. This function is still needed for gravity infusions, but the stands can be extended higher than the height level of the door frames (see Fig. 20). This means that the patient cannot go to the toilet or out of

the patient's room after a short gravity infusion. A mark on the bar indicating where the height of the door frame is reached was suggested by the group as a solution.

When asked how infusion stands are moved - in front of or next to the body - the group says "at 2 o'clock", while in the paediatric area infusion stands are moved by the parents next to the body in order to have a clear view of the child. Walking with the infusion stand is a challenge - especially passing through doors or entering lifts.

Data protection

In the areas of the respondents, there is no personalisation of the infusion stands; patient data is affixed to the respective infusion containers with adhesive labels. One exception is paediatrics: here, labels with the first name are attached to the hangers.

> *"In the hospital, everyone is sick, you can also have a tube" (quote from a nurse, second project meeting).*

Data and visual protection with regard to the outgoing and incoming systems is not considered important. This position is justified with the fact that there is no shame on the part of the patients in this regard, "...patients themselves are very interested in what comes out of their outlets and what that looks like" (quote from a nurse, second project meeting). At the same time, covers would prolong the nurses' rounds, as the condition and content of the feeding and draining systems could not be assessed at a glance. In the course of the conversation, the initial strict rejection of one interviewee changed: *"There is simply nothing like this yet. The question is how it would be accepted if the option existed"* (quote from a nurse, second project meeting).

Bottom part

> *"Well, I have never braked an infusion stand in my career" (quote from a nurse, second project meeting).*

Regarding the lower part of the infusion stand, it is reported that the castors are difficult to move. The interviewees would like to see larger castors to be able to cope better with obstacles,

and quieter running noises are also mentioned as a wish. One respondent reported that tripping over the infusion stand base was not an issue in the paediatric setting, as children would adapt very quickly to the changed movement situation. The previous locking brakes of the infusion stands are perceived as annoying. In general, the interviewees question the necessity of brakes, as hospital floors are usually flat and rolling away is therefore not an issue. A fastening option for draining systems by means of a "standard rail" (see Fig. 21) or similar is generally considered sensible.

Middle part

In the oncology departments of the interviewees, between one and six electronic devices (infusion machines, perfusers, etc.) and up to five infusion containers are attached to an infusion stand at the same time. One interviewee reports that the telescopic pole is twisted, which leads to the infusion and power plug cables being wound up and thus shortens the patient's range of movement. As a product improvement, a telescopic function is desired that can be operated with one hand and at the same time offers a safeguard against a sudden lowering of the upper part. Baskets or storage space for patients are not considered useful; the respondents also do not see the point of the common drip glasses.

Top part

During the interview, a maximum load of ten kilograms was reported for the infusion stands, although this was very rare. For short infusions, there is often a lack of suitable hangers, which is why glass infusion bottles are often attached to the hangers with plaster.

Conclusion

In summary, the majority of the wishes and requirements of the respondents can be found in the first list of requirements. The following new findings can be explored:

- Brakes are apparently not an issue for nursing staff in the hospital setting.
- Electrification of the infusion stand more present than previously estimated within the project.
- Securing against lowering of the upper part of the telescopic pole has not yet been considered.

- Data protection and privacy are not considered important for the infusion stand product. Product features such as covers or similar are largely rejected by the caregivers.

2.5 M 1.5: Requirements list adaptation II

The aim of milestone M 1.5 was to adapt the list of requirements by systematically collecting patient requirements.

In order to be able to ascertain the patients' requirements, two practice visits were arranged. In consultation with a university hospital, approx. 16 patients from four wards were to be interviewed qualitatively. Methodologically, the respective ward areas selected four patients the day before the survey and asked for their consent to participate in the study. The selection was criterion-based and based on an instruction guide, which was prepared in advance together with information material and sent to the respective wards. The selection criteria were:

- Age over 18 years
- Capable of consenting
- Experience with or current use of an infusion stand
- Sufficient mobility, can move independently with the infusion stand
- Interest and motivation to talk about the topic

The information material included consent forms for participation in the study as well as data protection consents, which were to be read and signed by the respondents beforehand. For possible queries, the participants could obtain information on this by telephone. Furthermore, sufficient time was allowed for further questions on the day of the survey.

The qualitative questioning was based on the questioning of the nursing professionals and focussed on requests to tell stories and the questioning of individual items, insofar as these were not mentioned by the interviewees. In order to be able to guarantee the least possible intrusion into the private sphere and areas of data protection, it was methodically decided in advance not to record the statements of the interviewees directly using audio technology. Since the aim of the survey was to collect product requirements and no in-depth interpretation of the patients' statements was to be carried out, a classic interview recording with

transcription and subsequent qualitative content analysis was not carried out. It was planned that the statements of the interviewees would be summarised by the responsible study staff member and then recorded in front of the interviewees. This way, only the voice of the study staff would be recorded and the interviewees would have the opportunity to correct the content. Unfortunately, this method turned out to be impractical on site, which is why the patients' statements were recorded as handwritten notes.

Data collection and analysis

Twelve individual interviews with an average length of approx. 30 minutes were conducted (n = 12; μ = 56 years; 7 ♂ 5♀). The interviewees were undergoing inpatient treatment at the time: neurology 4, urology 3, general, visceral and transplantation surgery 3, radio-oncology 2 participants. Four patients withdrew their willingness to participate on the day of the survey. The reason for this was exhaustion or the statement that they do not actually use the infusion stand. The notes of the individual interviews were digitised on the same day, categories were formed in the second review and finally assigned to six main categories.

Shame and data protection

In the category of shame and data protection, the necessity of covers for supply and drainage systems such as infusion therapies or urine bags is recorded. A majority of the respondents (7) state that they do not feel any shame regarding the draining systems. One patient reported "initial feelings of shame" that subsided with the duration of the inpatient stay.

One patient feels shame from her Redon drainage only in her home setting, while one patient states that he has no experience regarding draining systems, but imagines this situation to be shameful. Differences in shame regarding the drained fluid (urine, wound secretion, lymph fluid etc.) are denied by one patient. The majority of the interviewees state differences in the setting regarding shame. The danger of getting into a shameful situation is rated higher in public areas of the hospital - such as the entrance area - than on the ward. One patient states that the visibility of his urine bag is not a problem for him, but it could become a problem for others. The area of data protection has not been an issue for the respondents so far. While one patient sees it as a possible issue for individuals, one patient denies this: "not really important when you are unwell". When asked directly, four patients state that they would cover their discharge systems if this were easily possible.

Hygiene

When asked directly about the perceived cleanliness of the infusion stand, three respondents said it was "clean/hygienic" and six said it was "not clean/hygienic". Uncleanliness is perceived at the infusion stand base (dirty wheels, dirt and liquid residues on the flat surfaces of the base) and at the "patch suspension" for draining systems.

Braking

Brakes for reducing the rolling speed of the infusion stand are considered as not useful by all respondents. Parking brakes are not used when asked. One respondent states that she would have needed a parking brake in the hospital cafeteria due to an inclined plane, but did not use it due to lack of knowledge.

Risks of tripping

Respondents identify four potential or experienced trip hazards when using the infusion stand.

- Running into the infusion stand base and thus kicking against the infusion stand foot. This problem is exacerbated by turning the base during movement (and thus turning against the foot).
- The parking brakes of the individual castors with their mechanics.
- Lines of the draining systems such as drains or urine bags "dangling" in front of the feet.
- Long infusion lines that wind up on the stand or hang on the floor.

A frequently expressed wish of the interviewees is therefore a classification system for incoming and outgoing systems.

Add-ons

Transport options on the infusion stand (cup holders, baskets, etc.) are mostly positively received. The assessments of the potential benefits of transport options range from "would be a good idea" to "nice to have, but not absolutely necessary" to "cup holder would be exaggerated". One interviewee reports a situation in which she wanted to get a coffee in the patient kitchen, but was holding her drains in her left hand and had to guide the infusion stand with her right hand - she would have found a cup holder practical in this situation. One interviewee gives the advice not to overload the infusion stand with add-ons; easy handling would be important. A simple retractable hook would be sufficient for her as a transport option.

When using trans baskets or similar, one respondent would like to see a construction where "the dirt can fall through" so that the transport aids do not become a dirt trap.

An installed patient call on the infusion stand is considered useful with regard to the safety aspect. Especially when "being on the move with the infusion stand", this add-on would allow for an increased sense of safety "in case you overdo it, e.g. during a walk". One interviewee rejects a permanently installed patient call. There are enough bells in the patient's room and "how should the nurse know from where the patient rang the bell on the way?“.

An electrified infusion stand with a charging option (Schuko socket/USB connection) for electronic devices directly on the stand is given low priority or rejected by the respondents. According to the respondents, a charging option for patients would make more sense on the bedside table. An illumination of the bottom of the infusion stand base is positively received, as this add-on could be useful for elderly patients when going to the toilet at night. When asked what the lighting conditions are like in the patient's room at night, all respondents stated "very bright".

Some (5) of the respondents would like to have a thickened handle directly on the infusion stand. The use of a "fat grip" would facilitate manoeuvring with the product and offers a better grip feeling than stainless steel.

Two patients who have a power strip installed on their infusion stand expressed the wish to be able to attach the power plug cable to the infusion stand ("clipable"). One patient emphasized the importance of knobs on the base of the infusion stand as protection for walls etc. The loudness of the infusion stand when rolling is an issue for one respondent regarding going to the toilet at night ("clangs and is loud"), while one respondent is disturbed by the loud alarms of the infusion machines. The nursing staff would turn down this alarm at the patient's request, but it resets to the factory setting after 24 hours. The interviewee also said that the noise of the pump was very loud. He would therefore let himself be pushed into a treatment room at night to sleep, because the person in the bed next to him would have three continuous infusion machines in use.

Mobility

When asked in which radius the respondents move with the infusion stand, they indicate the following: Lobby/entrance area (4), ward level (3), room (2), outdoors (1). The infusion stand base is perceived as too "bulky and cumbersome", except for one statement. For one

respondent, the base is the "biggest disturbing factor of the whole product". One participant finds the base "good, because it is easy to get into the corners". However, the struts or the legs of the base "should be shorter". Six of the respondents state that they use the infusion stand as a support and thus as a mobility aid. Reasons for use are: Dizziness during initial mobilisation (1), because of a pre-existing multiple sclerosis (1) and because it is "the only thing you have" (1). Regarding the quality of support, one respondent feels secure with it, four stated that it is not well met and one person identifies the poor support as a potential tripping hazard. Two respondents stated that they were disturbed by hanging infusion containers and by infusion stands that were set higher than the respective door frame heights. The driving characteristics of the castors are rated as poor. The focus of the statements here is the tendency to block and the resulting preferential rolling directions (castors turn the base into the footstep when walking).

Conclusion

The selected patient access proved to be a suitable method. The pre-selection of patients by the respective wards and areas on the basis of a pre-prepared selection guide and a process description proved to be practicable and without problems in implementation. The note-taking of patients' statements in bullet points also proved to be very practicable, and the risk of loss of information in this regard was considered to be low. The results of the survey show that the topics of "shame" and "data protection" are only rated as important to a small extent by the respondents. While none of the respondents stated any concerns about data protection, the respectively perceived shame was dependent on the time and place. The visibility of urine and secretion bags in the respective ward areas are often perceived as having "little" to "no" shame. One reason for this could be the ubiquitous presence. For example, on urological wards the presence of a visible urine bag is shared by many people, or on surgical wards the presence of drains. If these patients go to other areas of a publicly accessible hospital, such as the entrance area and cafeteria, the feeling of shame often increases, as the probability of encountering people in this setting who do not share the "urine bag" or "drainage" situation increases. The question on data protection showed that the majority of the patients interviewed did not think about this before the interview. However, the tendency could be similar to shame. If, for example, chemotherapeutic drugs are openly discussed in the respective oncology areas, it is potentially possible that those affected do not want to show

this openly in the cafeteria. An optional cover for the delivery and supply systems is therefore considered useful and necessary. Dirty infusion stands are perceived by many of the interviewees and thus often evaluated negatively visually. Installed brakes are needed for possible inclined levels and ramps in the sense of a parking brake. Brakes to slow down the rolling speed, however, are not. In addition to the already known risk of tripping due to "stepping against the infusion stand base", the interviewees confirm the potential risk of falling due to inflow and outflow systems. Especially in the case of very long infusion lines or several and simultaneous drains, there is a risk that patients step on the lines or get caught on them. In this regard, the wish for a tidy system for supply and drainage systems - such as line holders - was expressed several times. Transport options, for example cup holders or baskets, are received differently - but mostly positively. However, these types of infusion stand add-ons are often perceived as additional comfort that should not be absolutely necessary and should in no case make infusion stand operation more difficult or require additional work steps (more difficult cleaning). Regarding possible additional electronic functions, a patient call was very positively received as a safety aspect. Schuko sockets or USB ports for charging electronic devices such as smartphones and tablets were not felt to be necessary. In this respect, many of the respondents explained that such a charging option at the bedside table would make more sense and that this product should also be urgently revised in terms of functions and operation. The option of underfloor lighting at the base of the infusion stand is perceived positively, even if the prevailing lighting conditions in the patients' rooms at night are considered to be very bright. Many of the interviewees see the advantage of underfloor lighting in not having to switch on another light and they consider this electronic add-on to be potentially fall-preventive. The interviewees state that infusion stands are sometimes also used as a support. Especially within the initial mobilisation after surgical interventions or if the users already need mobility aids before the infusion therapy, a support function is needed. Thus, the situation arises that the infusion stand is used for other purposes than as a support and mobility aid, sometimes due to a lack of alternatives.

Strategic purchasing and end-user involvement

One aspect that arose during the project work was the question of how new products find their way into the everyday practice of hospitals. The background to this question was the realisation that there are already partial evolutionary developments for requirements on the

technology market, but these often did not find their way into practice. An example of this phenomenon is the statement of a manufacturer that hospitals would not be willing to pay a higher price for a quieter infusion stand. Since there was no specific knowledge about procurement or strategic purchasing in hospitals within the project group, telephone interviews were conducted with the purchasing department of a municipal hospital and the strategic purchasing department of a university hospital. In both of the approx. 30-minute conversations, the insight was gained that the purchase price plays an important role in product selection. Both interviewees justify this with the striving for economic efficiency and the responsibility as an institution under public law. However, both state that the product price is "not the only selection factor" in the acquisition of new products. If the technical benefit of a potentially more expensive product exceeds that of the cheaper one, the purchase price factor is abandoned. However, this technical added value must be determined, proven and formulated by the end consumers. Both interview partners state that they do not have the necessary market overview of the respective products. They develop selective knowledge about individual products through repeated purchases; however, the range of products and their alternatives on the market is too large. As a result, the purchasing managers are dependent on the knowledge and suggestions of the end users.

A deputy head of department participating in the project group reported on her acquisition process regarding new infusion stands. The background for the new acquisition was dissatisfaction with the technical solutions of the products currently in use. She got a market overview by researching the internet and the product catalogues it contained. According to her, the acquisition of the products preferred by her department is "lengthy" and requires the support of the deputy head of nursing. In summary, the implementation of new technologies and products in practice seems to be strongly dependent on individual actors in leading positions. This thesis is confirmed by both interviewees from purchasing divisions, who identify the end user as the most important factor in evaluation and selection. However, the acquisition of a market overview of the respective products is unsystematic and happens arbitrarily - depending on the strengths and weaknesses of the individual end users.

Hygiene

Another topic area that opens up within product development concerns the often-described poor hygienic condition of infusion stands - with the main problem areas being the base of the infusion stand and the castors. Discussions in the project team and descriptions from the respective user groups reveal a certain discrepancy between the large number of contaminated rollers and their low profile in the literature. This is surprising, as it can be assumed that poorly rolling infusion stands are not uncommon in the respective practice facilities and that this problem can be transferred to all mobile objects such as beds, bedside cabinets, dressing and bed trolleys, etc. in hospitals (Elsbernd et al., 2022). Therefore, databases and search engines were searched for interdisciplinary solutions and topics to be dealt with, and a hospital hygiene officer was interviewed about the prevailing cleaning practices. It should be noted that cleaning work in hospitals is primarily carried out by cleaning staff, but nursing staff also clean surfaces and equipment. Regarding the cleaning of floors or surfaces, there are detailed regulations and legal principles of the Commission for Hospital Hygiene and Infection Prevention (KRINKO) of the Robert Koch Institute (2004) as well as in-house hygiene plans against the background of quality assurance. The cleaning of bedside cabinets and hospital beds is regulated by the S1 guideline "Hygienic preparation of patient beds" (Working Group "Hospital & Practice Hygiene", 2016) - however, this does not explicitly refer to the cleaning of the rolls. The situation is similar in the maintenance instructions of an infusion stand manufacturer (Servoprax, 2015). In both regulations, the use of a "wipe disinfection" is recommended, which should presumably also be used for cleaning the reels. However, wipe cleaning and disinfection is difficult to implement in the area of wheels and castors, as accessibility is very difficult due to covers, brakes and proximity to the floor. In addition, not all dirt can be removed from the castors by wiping. Discussions with nurses and a hygiene officer confirm that the cleaning of infusion stands and thus the cleaning of castors is the main responsibility of nurses. Thus, the situation arises that due to the difficulty of cleaning the rolls and the often high workload of the nurses, hygienic reprocessing usually does not take place and the rolls become unusable over time due to dirt and rust. According to the hygiene officers, the focus when cleaning the rolls is on visual cleanliness, since floor surfaces are considered to be contaminated in principle. Daily wipe disinfection is therefore only carried out on the infusion stand parts that are also touched (middle part and top part). In general, the following questions arise when dealing with roll hygiene:

- why this work is located in the area of nursing care,
- who has the implementation responsibility for rolling equipment that is not used by nursing (sonography equipment etc.) and why these are presumably cleaned by cleaners - but others (such as infusion stands) are not and
- why the cleaning of castors is not technically supported - considering the fact that many mobile objects cannot be turned due to their own weight (Elsbernd et al., 2022).

According to a well-known manufacturer of cleaning systems, good role hygiene begins with the cleanliness of the floor - which in turn makes the extensive regulations on floor and surface hygiene comprehensible (Nora Systems, 2013; Robert Koch Institute, 2004).

Results of the second project phase and generating of the second list of requirements

The second phase of the project focused on the validation of the list of requirements I drawn up within the project by means of requirements surveys of infusion stand users. The results obtained here show a requirements profile for the respective infusion stands that varies in part depending on the user group. In addition to the respective user (patient, nurse, etc.), it is primarily the context of use that forms the basis for the variously formulated requirements. For this reason, it is understandable why electrification of the infusion stand is given higher priority in equipment-intensive areas such as radiation oncology than in urology, which in turn prioritises the suspension of urine bags from the middle section or the overhead suspension of heavy irrigation bags. Additionally, against the background of their daily work organisation and processes, nurses formulate different requirements (easy and fast cleaning, reduction of muscle strain, safe infusion therapy, etc.) than patients who benefit from transport options, gait support and, above all, easy manoeuvrability. In addition to this multitude of requirement factors, there are economic and hygienic specifications or guidelines that result in a very complex requirement profile for infusion stands, which cannot be realised by a single model or hardly at all (as is the case with the common infusion stand). Apart from this complexity, however, general requirements for data protection, hygiene, safety, economy, and design can be formulated and found in all application contexts.

The survey of requirements in practice by the two main user groups - patients and caregivers - and the use of focus groups (caregivers) and individual interviews in the field (patients) also produced new findings on the requirements for and the use of infusion stands. Here it is shown that infusion stands are used much more frequently by patients for gait support than was assumed internally at the start of the development project. In addition, the patients interviewed estimate the necessity of add-ons such as USB connections or transport baskets etc. to be much lower than assumed. Statements such as "Future infusion stand developments should not be overloaded with add-ons" or "A hook would suffice as a transport option" can be understood here as an appreciation of the pragmatic and functional properties of the infusion stand commonly used to date.

After the collection and analysis of the respective user requirements, the generation of the second list of requirements took place. The addition of new requirements and corrections of already formulated requirements form the basis for this.

Generating requirements list 2

General requirements

G1 Data protection

G1.1 For outsiders, the type of infusion therapy (especially drug name) and the draining systems (e.g. drains) are not recognisable.

G1.2 Data that can be linked to patients are not stored (e.g. GPS).

G2 Hygiene and environment

G2.1 The individual components are disinfectable and easy to clean.

G2.2 The surfaces are not damaged by common disinfectants and cleaning agents

G2.3 The individual components have been developed in a resource-saving way and are recyclable in terms of a sustainable product cycle.

G3 Saftey

G3.1 The infusion stand is tilt-proof and can support the user if needed.

G3.2 The infusion stand stands securely and immovably when the brake is applied.

G3.3 The parking brake is operated centrally. The brake can also be operated with little grip strength and fine motor skills.

G3.5 The infusion stand conveys a feeling of safety due to its stable construction.

G3.6 The possibility of personalisation is available. This prevents patient or medication mix-ups.

G3.7 There is an order system for supply and discharge lines. The arrangement of the pipes reduces the risk of accidents and ensures compliance with the hygiene guideline.

G3.8 A patient call is appropriate. Users can call attention to themselves in emergency situations.

G4 Economic efficiency

G4.1 The infusion stand and its modular parts must be space-saving and efficiently storable.

G4.2 Individual parts of the infusion stand must be easily replaceable in case of a defect.

G5 Design

G5.1 The end product can be operated by people regardless of their height or the physical strength they have to exert.

G5.2 The chosen design of the infusion stand is intuitive and self-explanatory to use, regardless of the user.

G5.3 The infusion stand promotes or ensures the mobility and thus the self-determination of the user.

G5.5 Electronic devices such as infusion pumps, perfusors or electronic drainage systems can be charged centrally via a power source in the room and the storage.

Special requirements of individual components

S1 Bottom part

S1.1 The base of the infusion stand is designed to allow physiological/safe gait. This means that the step length can be freely selected and the user's gaze is detached from the base of the infusion stand.

S1.2 The wheels of the infusion stand are non-slip even when wet on different floor structures, such as various plastic floors and tiles.

S1.3 Unrestricted mobility of the infusion stand in all directional axes is possible in a confined space.

S1.4 The wheels of the infusion stand overcome obstacles such as thresholds and lift edges without any problems and without much effort.

S1.5 The wheel arch noises are quiet on the different ground structures.

S1.6 The wheels of the infusion stand are without grooves and crevices in which dirt etc. gets stuck.

S1.7 The infusion stand independently maintains the track/line of travel and the base does not turn into the footstep.

S1.8 The wheels and base clean themselves with built-in brushes.

S1.9 The base has underbody lighting, making it easier to walk in dark rooms.

S2 Middle part

S2.1 The infusion stand is easily height-adjustable for gravity infusions without effort.

S2.2 Drainage systems such as urine bags and other drainage systems can be easily attached.

S2.3 Infusion pumps and perfusers can be securely attached at chest height and do not obscure the view when pushing the stand.

S2.4 There are simply kept storage areas and a suspension for transporting smaller items and drinks.

S2.5 Optional heavy items such as oxygen cylinders can be securely attached.

S2.7 Thickened grip on the middle part (fatgrips) for easier and more comfortable operation.

S2.8 Marking on the centre section to indicate the door frame height when the infusion stand is extended.

S3 Top part

S3.1 The infusion stand includes a built-in holder option for glass bottles (volumes 50 ml to 500 ml).

S3.2 The holding devices are designed in such a way that up to four bottles and infusion bags can hang from them at the same time.

S3.3 The muscular strain caused by overhead work is reduced. Injuries are thus prevented.

S3.4 Retaining devices that are not needed can be folded away.

Comments on the addition and correction of existing requirements

With the help of the following comments and justifications, the adaptation of the product requirements and thus the generating of the second list of requirements is to be presented transparently and made comprehensible.

G3 Saftey

G3.1 Addition of "and can support the user if necessary" to the property "tilt-proof”

Explanation: Patients report situations (such as initial mobilisation after surgery or general dizziness) where the infusion stand is used for gait support.

G3.7 Addition of a classification system for incoming and outgoing systems (line management)

Explanation: Patients report tripping hazards due to drains and urinary catheter lines hanging down due to accidentally stepping on them. Lack of cable management causes infusion lines to become coiled. This results in a shortened range and an increased risk of catheter dislocation.

G3.8 Addition of a patient call

Explanation: The users rate the possibility of being able to draw attention to themselves in an emergency as high and important.

G5 Design

G5.4 Request removal

Explanation: The users see a low demand for an electrified infusion stand with existing large implementation hurdles (price/resource expenditure of accumulators)

S1 Bottom part

S1.7 Addition of the supplement "Infusion stand base does not rotate unintentionally"

Explanation: Users report infusion stands spinning into the walkway.

S1.8 Removal "at the charging station”

Explanation: See item G5.4

S2 Middle part

S2.4 Addition "kept simple" and "one suspension”

Explanation: Feedback from patients not to "overload" the infusion stand. Simple and functional transport options such as a hook or similar are sufficient.

S2.6 Removal

Explanation: See item G5.4, Patients see no need to charge a smartphone on the infusion stand.

S2.7 Addition of a handle thickening in the sense of Fatgrips

Explanation: Touching bare metal is considered unpleasant. A thickening on the handle additionally facilitates manoeuvring with the infusion stand.

S.2.8 Addition of a mark on the centre section indicating the door frame height

Explanation: Patients report that the infusion stands are too high and that doors can no longer be passed (e.g. toilet door).

3. Detailed presentation of the project results and achievements of the second work package (responsibility Prof. Meinecke)

3.1 M 2.1: Technical framework

From the engineering side, a national and international product overview was first compiled and key suppliers and their developments identified. To illustrate the product, infusion stands and various infusion containers and materials were procured and examined. In addition, contact was made with several manufacturers and with medical supply stores. Basic questions about the use of the product were clarified within the interdisciplinary project team. For a deeper understanding of the product, an initial prototype was developed on the basis of an existing solution. The survey of the technical framework conditions could thus be successfully designed and is classified as successful.

3.2 M 2.2: Input for users

The creation of an input related to technical framework conditions was carried out via video calls and had two addressees. The first addressees are embodied by the nursing science part of the project in the form of Prof. Dr. Elsbernd and the associated research assistant, both of whom have many years of experience in using the system. Input took place here in the collegial exchange within the project meetings. The second addressees in the first phase were the nursing staff of Prof. Dr. Elsbernd's student project group. Input took place here in joint interdisciplinary video call sessions involving two mechanical engineering bachelor students. The increased understanding of the respective disciplinary solution/problem-solving strategy, communication patterns and subject-specific focal points is emphasized as a qualitative success.

3.3 M 2.3: Conception requirements list 1

The initial list of requirements formulated by the nursing science team was operationalized by Prof. Dr.-Ing. Meinecke and her research assistant into concrete technical development steps and transferred to subsystems of the infusion stand. User participation within the technology development of the infusion stand can thus be considered successful in the first step.

3.4 M 2.4: Product increment 1

Chassis

Based on problem reports from practice and from isolated literature sources, weaknesses and susceptibility to operating errors of the previous chassis design increasingly became a concise topic of technical development, which is why this element was focused on within the project. The following aspects were explored as the greatest product weaknesses of the trolley design used to date:

- Risk of falling by stepping into the undercarriage while walking
- Turning the chassis into the travel path
- Lack of support for unsteady gait or weakness
- Large space requirement for storage of the infusion stands

The development of the new chassis was determined by the users' desire for a safe and at the same time highly mobile infusion stand. Infusion stands should provide users with a sense of security by allowing them to use them as a reliable support or to attach heavy irrigation catheter bags, for example. At the same time, infusion stands must be maneuverable in confined spaces and - from the point of view of work organization - take up as little space as possible in hospital rooms or storage areas. These strongly competing requirements of safety and mobility are forcing technical development into a critical balancing process.

The following chronologically documented steps in the development of the chassis design were taken with the aim of developing an infusion stand that is as safe as possible and at the same time as mobile as possible.

Front push trolley – see figure 1

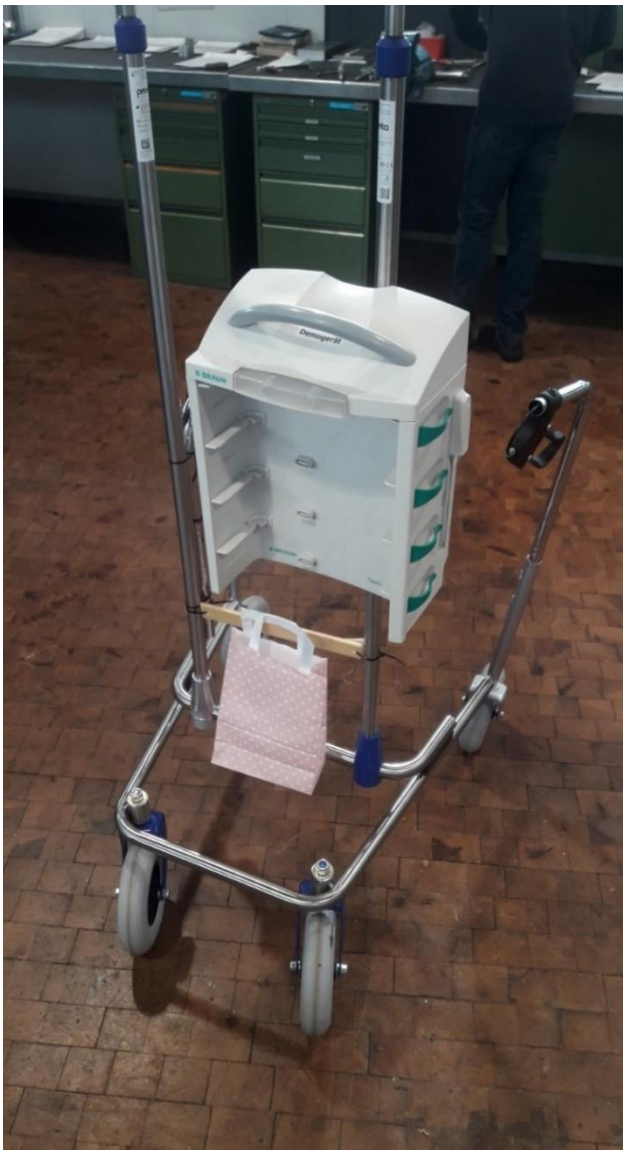

Figure 1: Front push trolley (CArCaSy, 2021)

The front push trolley is a combination of the Eco-Move infusion stand from Provita Medical (provita medical, 2022) and a standard rollator. The original castors of the Eco-Move were replaced by rollator castors (rear castors fixed, front castors free-moving) and the rollator handles including braking system were adopted. In addition, two infusion stand bars with one-hand height adjustments (Provita company) and a multifunction bar for attaching draining systems were added. The ability to accommodate two support bars on the front transfer trolley provides more suspension options with a low center of gravity and optimizable distribution. Of course, the front transfer trolley can also be equipped with only one retaining bar as usual. This design focuses on the requirement for safety. The anti-tilt trolley design with two-handed grip option and the use of an active braking system and parking brake enables - compared to the infusion stand design used up to now - a much safer product application with regard to the risk of falling and gait support. At the same time, walking "in the product", similar to the way rollators are used, creates a protective and comfortable space around the user.

The size and the perceived weightiness of the front sliding arm must be mentioned as a disadvantage. The focus on application safety by means of a broader design basis and the use of the rollator principle automatically results in disadvantages with regard to maneuverability, which is why this initial development is also to be understood as a theme-opening design.

U-shape – see figure 2

Within the project-internal evaluation of the front push trolley, the advantages of "walking in the product" and the resulting comfort space were assessed as an innovative solution against stepping against the infusion stand base and thus the risk of falling. For this reason, it should be possible in future chassis designs to step into the infusion stand or walk into the chassis. At the same time, the design should be space-saving and easy to maneuver.

Figure 2: U-shape chassis (CArCaSy, 2021)

The U-shape design, derived from the basic frame of the push trolley, is the first implementation of the new chassis requirements. The U-shape enables the user to step into the product without the bulkiness and impact of a walker, while at the same time saving space. The extendable leg (see Fig. 2) allows the trolley base to be adapted, thus increasing product stability, which is required, for example, for heavy loads or for aisle support. The U-shape makes it much easier to navigate in confined indoor spaces such as toilets/bathrooms, but with reduced tilt resistance and a preferred direction when walking (guidance only possible with the right hand), which severely restricts the user.

X-shape – see figure 3

The X-shape design was developed with the aim of counteracting the reduced tipping safety of the U-shape. For this purpose, the center of gravity of the infusion stand base was moved further to the center of the chassis, resulting in a significant increase in tipping safety. In a next step, the front wheels of the chassis were moved further outwards, thus further widening the base area. Overall, this makes the X-shape design significantly more tip-resistant. At the same time, the center of gravity shifted to the middle and the extendable wheel, as in the U-shape, take up

Figure 3: X-shape chassis (CArCaSy, 2021)

more space and thus offer less room for a free gait or for a freely selectable and physiological stride length compared to the U-shape.

Disc base and the A-shape

Figure 5: Disc base (CArCaSy, 2021)

Figure 4: A-shape chassis (CArCaSy, 2021)

In order to be able to approach the complex topic of the position of the wheels vs. stability and flexibility in an agile and explorative manner, a disc construction was developed purely as an object of investigation (see Fig. 5). Due to the individually adjustable infusion stand feet, the disc base can be used to represent a wide variety of angles and lengths - and thus different base variants. The A or arrow shape (see Fig. 4) resulted from the findings of the angles and cantilever lengths created by the determination matrix. The new basic shape of the design base increases the tilt resistance; the design center of gravity (support of the infusion stand rod) was moved further down, and the use of large wheels makes the trolley run more smoothly.

3.5 M 2.5: Product increment 2

In-project chassis investigations and a study paper showed that the A-frame can be improved even further in terms of tilt resistance by using "cantilevers“.

Within the project, the A-shape was evaluated as a significantly improved basic chassis design. The A-shape allows several options for foot positioning and an individual driving style, so that there are no qualitative disadvantages when guiding with the right or left hand.

Design finish – see figures 6 + 7

In the design finish of the A-shape, the design was finally revised without changing chassis characteristics. The tip is clearly flattened to avoid possible injuries during use. The outriggers are integrated into the frame and the rear wheels are straightened to further optimise the space requirement.

Figure 6: Design finish of the A-shape chassis (CArCaSy, 2022)

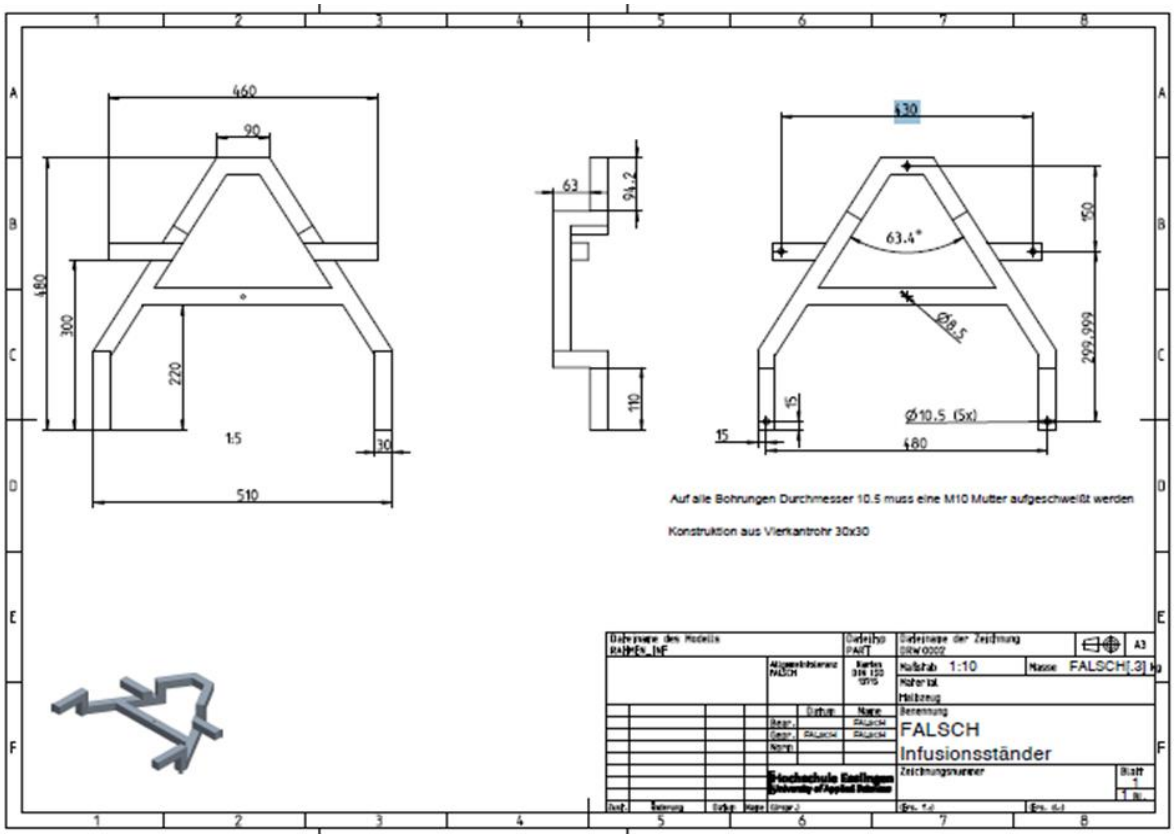

Figure 7: Engineering drawing A-shape chassis (CArCaSy, 2022)

Alternative solutions

In addition to the new design of the infusion stand chassis, alternative solutions could be found for individual existing problem areas. A simple and cost-effective solution is the retrofitting of standard infusion stand models with the addition of a spring roller (see Fig. 8). This creates a preferred direction that prevents the trolley from turning against the path of travel. It should be noted that the length of the spring roller used has an effect on the manoeuvrability and therefore on the turning circle.

Figure 8: Spring roller

3.6 M 2.6: Product increment 3

Within this milestone, a possible electric drive concept for the infusional stand chassis and further product increments - in the sense of add-ons - were developed.

3.6.1 Development of a drive concept for a new infusion stand for use in clinical practice

Another development option for the infusion stand base is a possible electric drive concept for clinical use. This approach only served to open up the technical topic - without the claim of a driven chassis of the CArCaSy prototype. Rather, the feasibility and limitations of an autonomously following vehicle base were to be investigated here, the findings of which could be implemented in later product developments in the form of autonomously following infusion stands, tables, serving trolleys, etc.. Such a development could, for example, detach the user's "guiding hand" from the infusion stand when using an infusion stand and thus enable new possibilities and freedom. This would make it possible to carry objects with two hands (e.g. a meal tray), to use mobility aids (forearm aids on both sides, rollators, etc.) and, by "following" the infusion stand, the user's walking distance would remain unimpaired.

Technical implementation of an electric drive concept

The thematic introduction and thus the foundation was the practical implementation in a Bachelor's thesis - "Development of a drive concept for a new infusion stand for use in clinical practice" (Mataraci 2021) - by a mechanical engineering student.

The main interest of this work lies in the type of drive of the undercarriage, whereby in this implementation each of the five undercarriage assemblies was operated and controlled separately via an electronic motor. Each landing gear assembly consists of a motor, gearbox, ball bearings and omniwheels (see Fig. 9). The individual control enables different speeds and directions of rotation of the respective omni-wheels, which are needed to be able to manoeuvre in the desired directions of travel. In this model, the infusion stand is controlled via a central control on the infusion stand middle section.

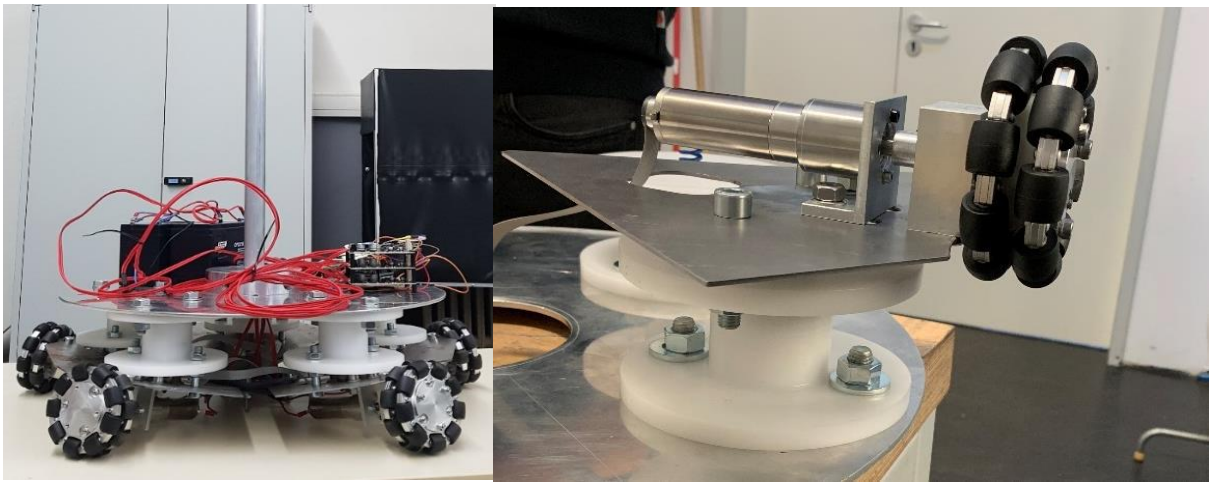

Figure 9: (left) Assembled powered chassis, (right) single chassis module (CArCaSy, 2021)

The acquisition of an autonomously following case (Cowarobot) was the prelude to the development of an autonomously following infusion stand. The Cowarobot is an autonomously acting case that follows its user by means of optical sensors and can automatically adjust its speed. This enables the Cowarobot to avoid obstacles and stay close to the person without the user having to carry a remote control or a chip in the form of a transponder. In principle, it is possible to adapt the system for an autonomous infusion stand, but unfortunately the tilt safety and reliability were not sufficient.

Tests were then carried out with the Robotino 2 and Robotino 4 from Festo Didactic (see Fig. 10). It was shown that today's autonomously driving systems can be used as reliable and stable autonomous infusion stands. However, the systems are still technically very complex and also economically far away from the usual budget for an infusion stand, so that although it is technically possible, it is not yet practically feasible.

3.6.2 Product increments „add-ons“

Chassis lighting

The use of "underfloor lighting" was evaluated by the users as a safety aspect and additional comfort. Illuminating the footwell can make it easier to recognise potential fall hazards in good time, especially at night. In addition, the light load in multi-bed rooms can possibly be reduced, as currently the main lighting usually has to be switched on when patients on infusion therapy have to go to the toilet or similar - with the result that fellow patients usually wake up as well. From a technical point of view, the illumination of the undercarriage base was pursued via two approaches: an active approach via direct illumination by LED strips with pressure switch or motion sensor and a passive approach via the application of a fluorescent paint and likewise fluorescent adhesive tapes (see Fig. 11).

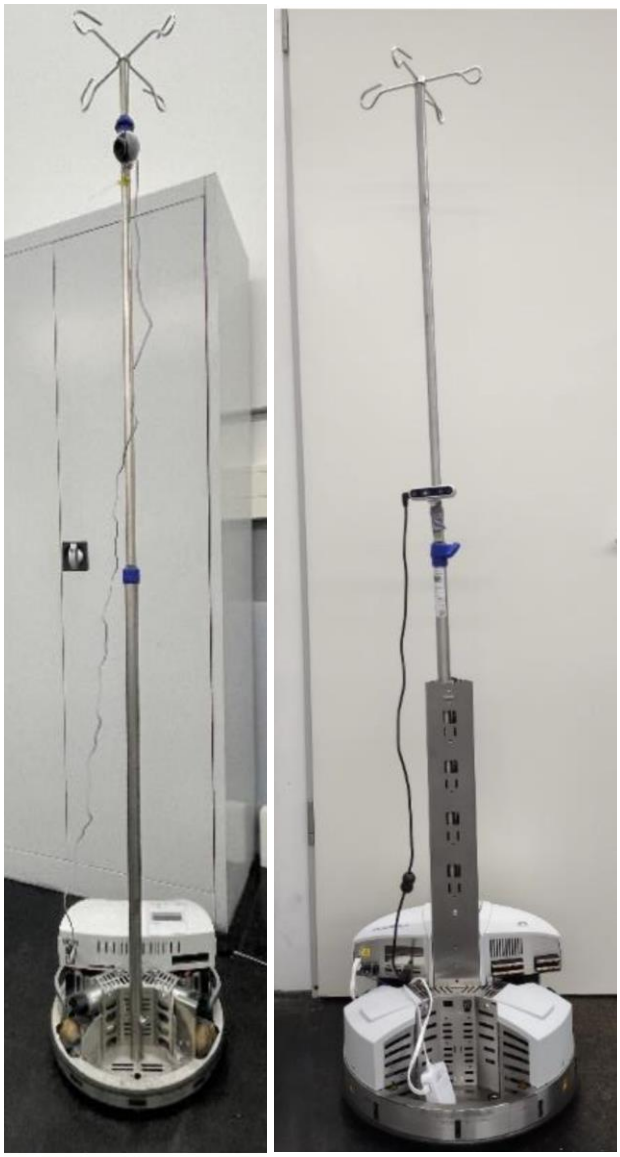

Figure 10: IV pole assembly on Robotino 2 (left) and Robotio 4 (right), both Festo Didactic (CArCaSy, 2021)

Attachment and covering of draining liquids

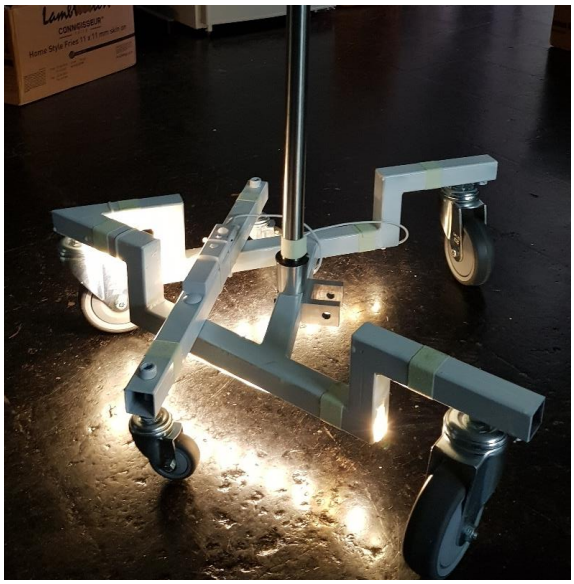

Figure 11: Chassis lighting (CArCaSy, 2021)

The need for a technical solution regarding the attachment and covering of draining fluids can be explained from two points of view. In the most common case, patients ultimately lack suspension options on which they can safely place their (sometimes multiple) catheter and drainage bags. This leads to drainage bags and bottles being attached to the patient's clothing, catheter bags being hung on the trouser pocket or having to be carried in the hand - often resulting in artificially produced tripping hazards, possibly with the risk of catheter dislocation and hygienically problematic situations.

Figure 12: Hook suspension (CArCaSy, 2022)

Therefore, a simple hook suspension was developed as an option (see fig. 12), which can be supplemented with multiple hooks or by adding a standard medical rod (e.g. for electronic suction drains) as required. Magazine solutions or covers as with the upper suspension are also possible.

In addition, the clinical requirements survey of this project study shows the possibility of shame development owing to the visibility of body fluids draining from patients. Due to the very limited time frame, this necessary aspect could not be finally dealt with from a technical point of view. However, covers of a suitable size would also be conceivable in this respect. As a short-term and possibly inexpensive alternative, the use of bags or similar that the users could hang on the hook construction would also be imaginable.

Connecting element

The infusion stand telescopic pole with its possible add-ons handle, transport option and organisation systems is summarised within the assembly group connecting element. Within the technical development, telescopic rods for one-hand height adjustment from Provita were used almost exclusively, which were kindly made available to the project.

Handle and transport options

Usually, infusion stands are moved and guided by the infusion stand telescopic rod. The use of handles - if implemented in an ergonomically sensible way - enables easier manoeuvrability

Figure 13: Handle and transport variants (CArCaSy, 2022)

and/or the possibility of guiding the infusion stand with two hands, as shown in the front push trolley variant. For this, the grip thickness and surface must be designed appropriately and intuitively, and pleasant materials must be chosen in order to achieve the greatest possible added value. An example of this is the steering wheel development of the last century. In principle, three variants were developed (see Fig.13).

Handle thickening of the infusion stand pole

The handle thickening of the middle part can be classified as the most uncomplicated variant, as it is the easiest to retrofit and the stand can be guided as before. The enlarged grip surface makes it easier to grip the infusion stand pole - an advantage especially for people who have problems with grip strength or sensory deficits (e.g. polyneuropathies).

Two-sided folding handle

The use of a handle that can be folded on both sides enables the user to guide the infusion stand either in front of him/her by both handles or, as usual, only by one handle. The possibility of folding and unfolding the individual handles, in addition to other diverse application possibilities, results in efficient storage when not in use.

Handlebar

The handlebar corresponds to the usual handlebars of scooters or bicycles. It is not foldable, but therefore much more stable than the foldable handlebar, and in addition to an ergonomical shape, it offers further application possibilities such as hooks and eyelets for attaching utensils or tubes.

Further add-ons of the connecting element

During the processing of the user requirements formulated from practice, some sensible infusion stand add-ons could be worked out theoretically. The possible add-on ideas differ in their complexity, which automatically results in their feasibility. For example, a marking for door frame heights on the infusion stand telescopic pole can be implemented relatively quickly and easily, but the design of transport systems such as baskets, cup holders or similar cannot. Due to the limited time frame, these transport systems and a system for organising incoming and outgoing fluids could not be worked on or could not be finalised. Similarly, the patient call as a potentially useful safety feature could not be worked on in depth. The future implementation of a "patient bell" on the infusion stand could increase the perceived safety of use, especially for weakened persons, and (in combination with infusomats/perfusion alarms) increase application safety. At the same time, such considerations automatically raise the question of alarm implementation and its consequences: Is a simple optical signal (e.g. as a red lamp) sufficient as a decentralised alarm directly at the infusion stand or is a central alarm (cf. patient call systems) with optical and acoustic signal required? While the decision in favour of a decentralised alarm could be implemented without problems, a central alarm would make it necessary to locate the infusion stand (and thus indirectly to locate the user) and would mean a clear encroachment on data protection and individual privacy.

Suspensions

The assembly group suspensions mainly focuses on the suspension possibilities for infusion containers. These are attached to the upper part of the telescopic pole. Most of the considerations made here can also be applied to the suspensions for dispensing systems on the basic element of the infusion stand. When dealing with this assembly, three problem areas could be identified:

- There is often a lack of suspension possibilities for glass bottles (mostly short infusions 50-250 ml volume). This circumstance is countered in practice with plaster reins.
- If there are suspension possibilities for glass bottles, they will swing when walking and can pull on intravenous catheters if they swing strongly (e.g. over door thresholds and lift edges).
- In current practice, there is no simple way to cover infusion containers in a way that complies with data protection regulations. The use of black plastic bags for covering is currently only used for light-sensitive substances.

The solutions for the three problem areas developed here, among other things within the framework of a bachelor's thesis, were implemented and further developed:

A quick release piston is very suitable for the flexible attachment of suspensions and can be used for different round tube diameters. Since the final diameter of the round tube has not yet been determined and the profile has also not been finally clarified, the diameter range of 25 to 33.7 millimetres, which comes from the Provita catalogue, is adopted. A sheet metal holder offers the possibility to fix three bottle holders. Figure 14 shows the assembled state of the flexible suspension in the lower third of the connecting rod. There you can also see the round design; there are no sharp edges on which someone could get hurt. The fixed connection also prevents the infusion containers from swinging. Also in the picture, two preliminary studies for possible data protection-compliant covers for infusion bottles or bags, top: green, bottom: grey.

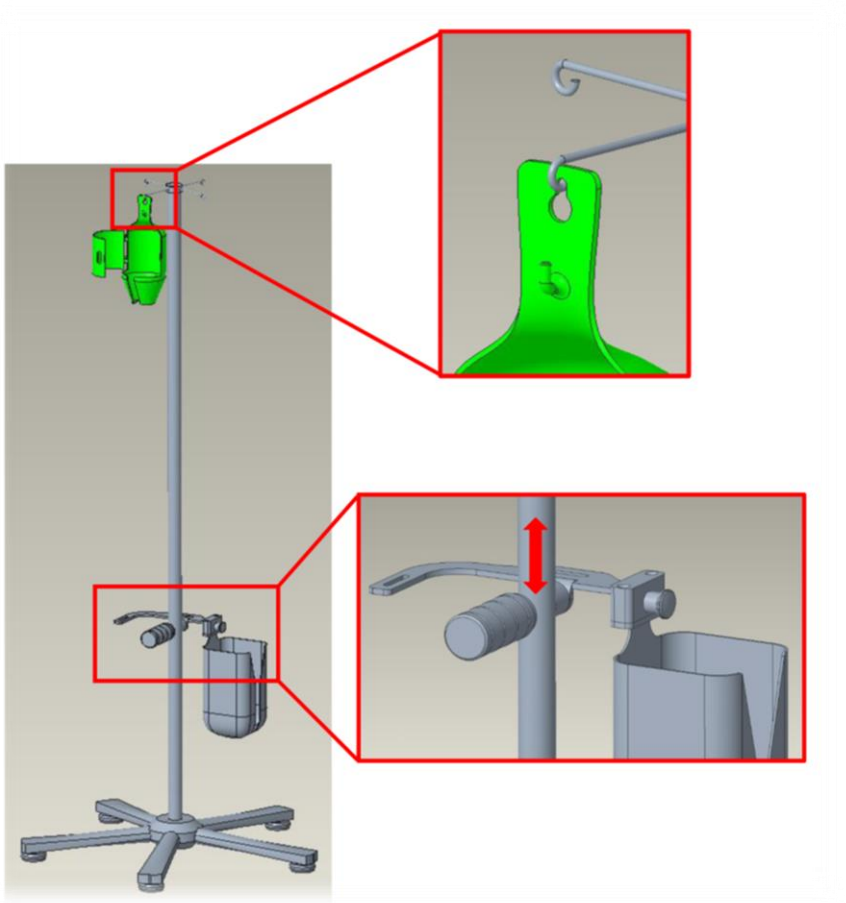

Figure 14: Suspensions (CArCaSy, 2021)

Magazine for holding the suspensions

A possible further development - especially for the upper suspension at the "head" of the infusion stand - is the magazine shown in figure 15. Here, the suspensions for different infusion containers can be flexibly hooked in. These then hang close to the infusion pole in a

space-saving manner and without the possibility of swinging. This contributes enormously to the stability, tilt resistance and smooth running of the infusion stand.

Suspension containers

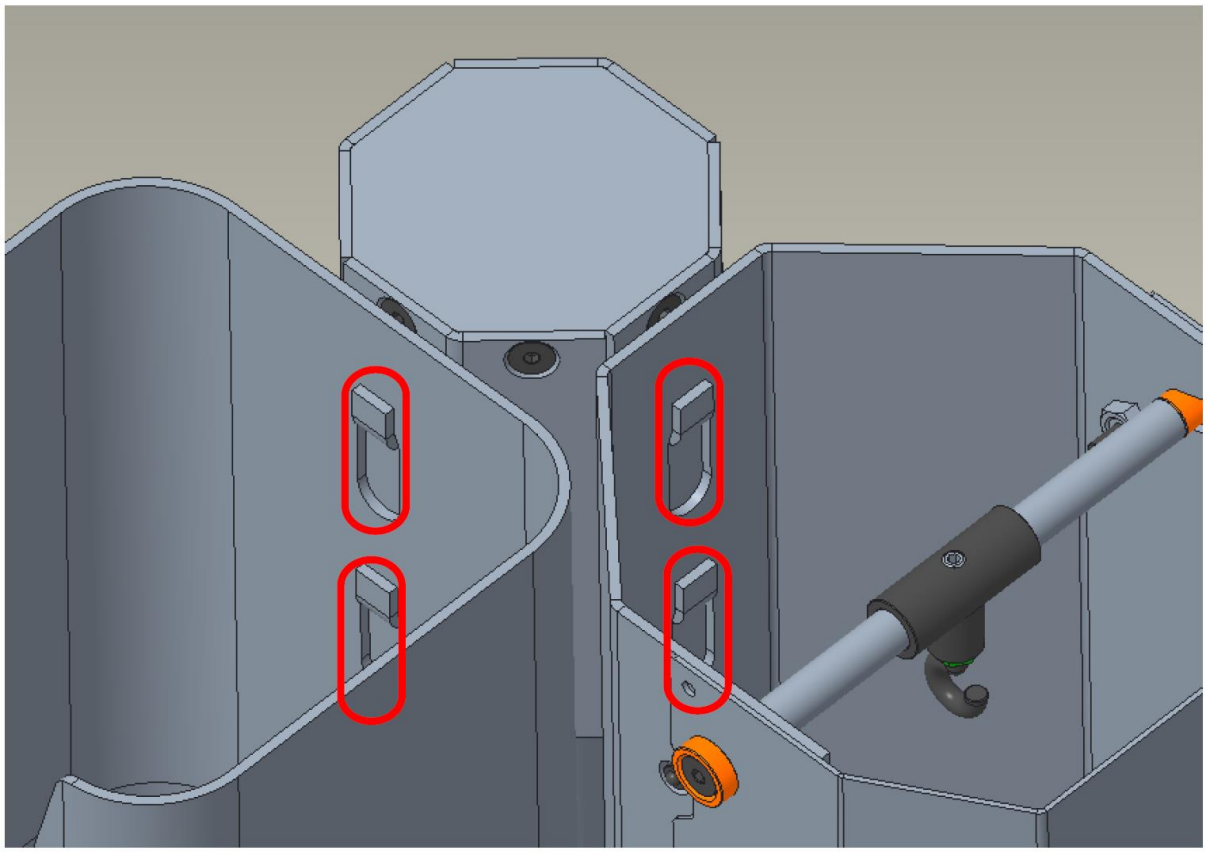

Figure 15: Suspension magazine (CArCaSy, 2020)

There were also various developments with regard to containers for holding different infusion bottles and bags.

Option A – see figure 16

With its harmonious shape, the prototype is visually appealing. The contents of the infusion cannot be seen by outsiders, but are easy for nursing staff who want to check the contents. The flap offers the possibility of conveniently inserting the infusion solution. This makes it possible to prepare the infusion solution and only then insert it into the holder. After the first practical tests, however, the disadvantages of the design become immediately apparent:

inserting plastic bottles is not possible with this concept. Dimensioning the model in such a way that plastic bottles fit conflicts with the accommodation of glass bottles.

Figure 16: Option A (CArCaSy, 2020)

Option B – see figure 17

To make the design user-friendly, a square profile is chosen. In this way, incorrect insertion of the bottle is immediately recognised by the operator and prevented. In the first design, the rectangular profile of the usual infusion plastic bottle was copied. In order to guarantee data protection but still make it easy to check the infusion, a continuous groove is incorporated. It offers sufficient visual protection for outsiders, but allows the nursing staff a quick view of the infusion. The groove is enlarged at the upper part of the component so that the insertion of an infusion is easier. The manufacturing process was also taken into account in the design. The model is suitable for the injection moulding process and optimised.

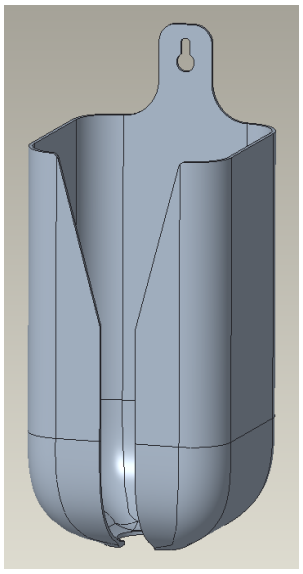

Figure 17: Option B (CArCaSy, 2020)

Option C – see figure 18

In this variant, data protection is also to be ensured by means of a flap. It can be folded upwards and completely covers the contents of the medication. This also protects the contents

from UV radiation. In order to be able to use infusion bags, the construction has a hook on which various containers can be hung. The flap is supposed to stay closed by itself with the help of gravity. Nurses can take a look at the infusion by actively opening it. For outsiders, this active action will be too much of an intrusion into the privacy of the stranger. A locking mechanism is also provided in which the flap locks in the upper position. This allows the infusion to be inserted without a further manual step.

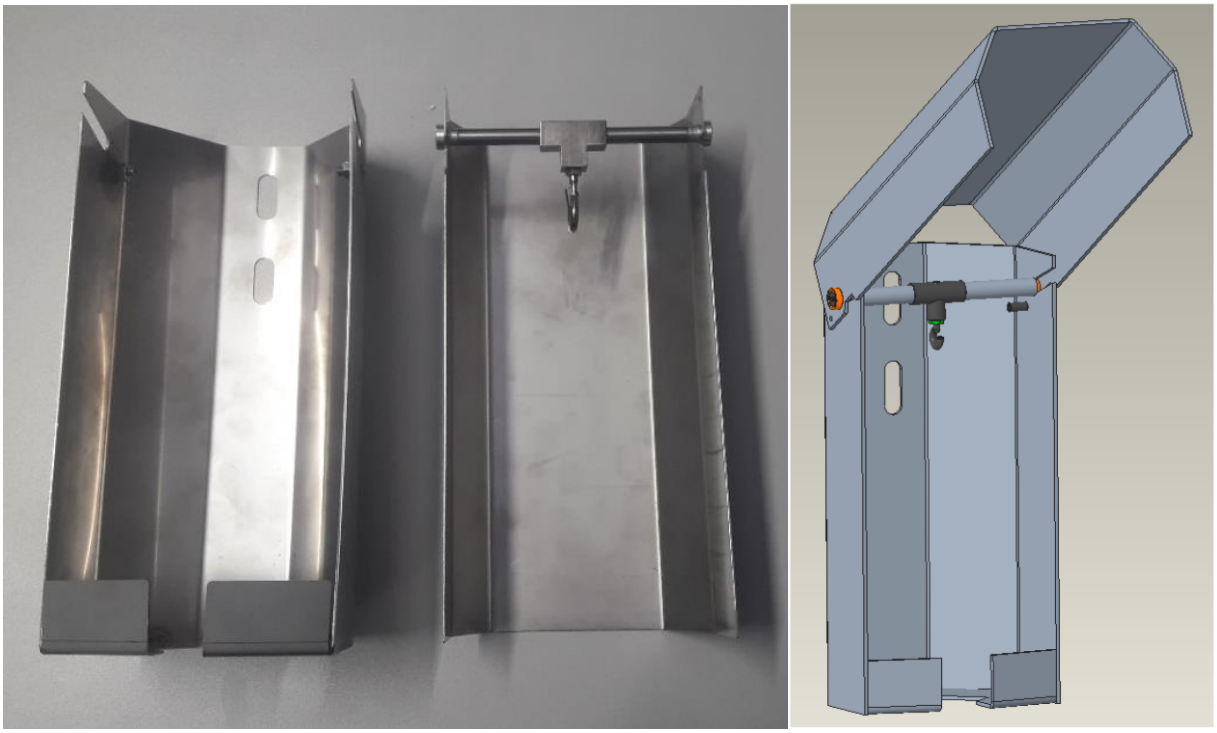

Figure 18: Option C (CArCaSy, 2020)

4. Final project milestones and conclusion

4.1 M 1.6: requirements list 4 and M 2.7: Prototype CArCaSy

A joint final event with the group of nursing experts took place on 04 May 2022. The practice group consisted of eleven participants from direct care and different care management levels. The aim of this meeting was to present the developed product designs and their development processes. For this purpose, the group was first provided with theoretical input in the form of a short slide presentation. The input content was a brief overview of the project work to date and the communication of basic knowledge on the evaluation of prototypes or product designs and technology increments. These contents were chosen against the background that an abstraction between product design and end product is often difficult for practical users and the evaluations desired by the project are often falsified or impaired as a result.

Survey of product designs and questionnaire

Three product design samples (see Fig. 19) were examined by small groups of three to four participants. The data was saved by means of short handwritten notes by the project team members, which were assigned to the respective product designs. The three product designs to be reviewed differ in terms of the guiding possibilities of the middle part and the respective suspension possibilities on the upper part. In addition, the designs have different add-ons such as undercarriage lighting and suspension or transport options on the middle and lower parts or undercarriage panelling. The newly developed undercarriage base and the one-hand adjustable telescopic bar from Provita form the foundation of all three product designs. With regard to the equipment of the undercarriages with castors, different product variants by the Blickle company are used.

The project meeting was concluded with a standardised survey using a questionnaire regarding further potential for improvement of technical aids for everyday clinical use. Within the survey,

Figure 19: Product design samples: III, II and I (left to right) (CArCaSy, 2022)

the understanding of abstraction between prototype or product design sample and finished

serial product was ascertained. Finally, the general conditions for possible future participatory integration in technology developments were also asked about.

Evaluation of the product designs

Chassis base/bottom part

The chassis base is perceived as very positive in terms of its running stability and applicability. The possibility of guiding the infusion stand in front of the person creates a certain form of protective sphere for the user and reduces the danger of stepping against the trolley base. In general, a smaller size of the base is desired - the smaller the better - and a stackability comparable to shopping trolleys in order to need as little storage capacity as possible.

The functionality of the different castors - except for the "brush with soft SoftMotion wheel" - is rated as very good. The reason for this: The brush construction can turn sideways and the driving resistance increases because the brushes drag across the floor.

The use of undercarriage lighting is also rated very positively. The energy supply should be provided by commercially available replaceable batteries (AA or AAA). From the point of view of the carers, the use of accumulators is often not practicable in practice. For example, rechargeable batteries are often overcharged and thus have a very limited lifespan; charging cables are missing or, in the hectic pace of everyday work, plugged-in mains cables are accidentally pulled out of the wall together with the socket. Switches should be operated by motion sensors so that the lighting does not cause light pollution and unnecessary energy consumption when not in use.

The advantages and disadvantages of undercarriage covers are evaluated and discussed in different ways. One of the main points of discussion is the cleaning of the equipment. If full covers are used, the cleaning requirement increases and, depending on the type of attachment, cleaning becomes more complicated. For this reason, some of the interviewees do not want any or only partial chassis covers so that, for example, infusion fluids can "drip through" to the floor and do not get into poorly accessible cover parts.

The possibility to attach drains and bags for draining liquids to the lower part is considered very important. Such a possibility in the form of a hook is only included on product design sample III, but should be installed as standard according to the respondents.

Middle part

The use of "soft handles" is generally perceived as very positive; however, no generally valid statement can be made about the type of handle. While a retractable handle is more practical for storage or when not in use, a fixed handlebar is considered to be safer or more stable (e.g. when leaning down or up). The handlebar should be combined with the infusion pole.
In general, infusion telescopic poles should be used in which the lower part of the telescopic pole is higher than in standard models. This is the only way perfusers and infusion machines, for example, can be attached at the correct working height. This is not easily possible with standard infusion stand models - the equipment is often attached to the moving part of the telescopic pole, which increases the risk of tipping over, or the respective nurses and doctors have to bend down or kneel on the floor to insert the equipment.

Top part and suspensions

The magazine for holding hangers is rated as a very good solution; in general, however, a setup in the form of two classic infusion hooks as well as one small and one large hanging container is desired. The respondents see opportunities and risks in removable suspension containers. Removable suspension containers could be put in a kind of dishwasher for cleaning - a less labour-intensive solution would thus counteract the high cleaning requirement of the containers expected by the interviewees. Permanently attached, i.e. non-removable suspension containers would reduce the risk of loss, but would have the aforementioned cleaning problem.

Analysis of the questionnaires

The standardised questionnaire was created using Evasys and filled out by hand by the nursing staff. Partly closed, partly open questions were used, which could be ticked in a pre-selection or/and answered in the free text area. Due to the small number of questions, the evaluation was done manually via Excel. The following areas were queried:

- Potential for improvement of technical aids in everyday clinical practice
- Abstraction between prototype and end product
- Methods and forms of interaction of future participatory technology development
- Participation within the product development phases

- Further suggestions

Potential for improvement of technical aids in everyday clinical practice

Within the recording of possible improvement potentials of technical aids, the products shower toilet chair, bedside cabinet, dressing trolley, rollator, standing-up aids and the mobile vital sign station (blood pressure indicator) were asked for as a preselection. In addition, the participants had the opportunity to supplement their statements in the free text area or to list further technical aids.

With the exception of the mobile vital sign station, the respondents see potential for improvement in all the technical aids listed. The shower commode chair is rated in one comment as insufficiently stable and dangerously tending to tip over during mobilisation. Other comments address the desire for mobile holders for oxygen cylinders and the unification or integration of IT and care aids in the previously used care trolley.

Abstraction between prototype and end product

For a targeted product design evaluation, the ability to abstract between prototype and later end product is essential in order to be able to evaluate individual product increments in a focussed manner away from the still possible raw design form. The questioning of these skills served to evaluate the input provided in advance and as a result shows a comprehensive understanding of the participants in this respect.

Methods and forms of interaction of future participatory technology development

While almost all participants could imagine taking part in prototype/product increment testing and creative workshops in possible future technology development processes, pure interviews in individual or group format seem interesting for only about half of the respondents. One participant could imagine participating in literature research or in surveys. With regard to interaction platforms, the majority of respondents are positive about face-to-face and/or online meetings. Only a small proportion of respondents can imagine an exchange in telephone meetings, purely written contact or digital project work.

Participation within the product development phases

The participants can also imagine a wide variety of fields of involvement within the respective product development phases. The majority see themselves primarily in the phases of problem analysis and prototype testing, while half of the respondents would be involved in eliciting product requirements and generating solutions.

Classification of the results

The results obtained in the assessment of the product design samples and the evaluation of the questionnaires show that carers are able to adequately assess technical artefacts and increments. Here, prior micro-training in the form of theoretical input can improve or promote and support the assessment skills and the quality of comments/criticisms. It is also shown that a large part of the carers would like to participate in active and practical activities (e.g. product evaluations). Only a small part of the respondents can imagine participation in pure or mainly theoretical activities such as literature research. In general, the desire is expressed to initiate further projects in the technology/nursing area in order to further promote the bridge between the faculty and the nursing area.

4.2 Conclusion

Infusion stands are a central aid in human health care. They are mainly found in hospitals, are usually in use for many years, sometimes carry enormous loads (e.g. irrigation solutions, perfusors), are also used by people with limited mobility to support walking, promote mobility and self-determination during ongoing infusion therapy and must be stored in sufficient numbers. Infusion stands are located in the patients' rooms, in the corridors, in the treatment and storage rooms. The danger of falling in the vicinity of the infusion stands is high for staff, patients and relatives. The weaknesses of the existing design of infusion stands are well known to the users. Nevertheless, for decades there has been no further development or adaptation to new, changed requirements, let alone to new technical possibilities, although the infusion stand is in great need of further technical and visual development. From the authors' point of view, a central reason could be the high price pressure in the health sector, especially in the field of medical aids. From an economic point of view, it may not be possible to make much money here and is therefore not interesting for the technical industries. Against this background, this research project has a special significance: this research is independent of economic interests and can thus defy market mechanisms. It is clear to the researchers that a

new product "infusion stand" must also assert itself on the market - but only when it is ready for the market and a certain level of competitiveness can be achieved.

Within the framework of this research project, three product design samples were presented to the user group "carers" in the last processing phase, which they analysed and evaluated in detail. All of the patterns focused on different development requirements. In a next step, a first prototype has to be developed from these patterns, which in turn prioritises requirements clearly.

The project shows that the technical development of aids cannot be detached from the users. In the case of this product "infusion stand", the focus is on two user groups: carers and patients. Both groups have partly different demands and wishes regarding the requirements to be fulfilled - this also against the background that the infusion stand accompanies the user group of carers in the working world and the user group of patients in the living world. Requirements are therefore formulated and prioritised differently. The discussion as to whether it makes sense at all to develop "only" one product "infusion stand" or whether it would make sense to develop different models for the main purposes of use - e.g. one for use outside or inside the patient's room, one for children, one for people with severely limited mobility, etc., possibly also in a modular way - has not yet been concluded.

In the short term, it makes sense to further develop the existing infusion stand models in an evolutionary manner in order to quickly improve the functions and mitigate the greatest weaknesses. The project team has shown that there are very simple, but in terms of functionality, safety and data protection very worthwhile adaptations that can and should be taken up by the industry. The redesign of the basic element alone brings so much improvement for the use of this aid that an industrialisation in several senses - for the individual and society - would be more than promising. Another revolutionary development is also to be initiated by the project. It is certainly promising to rethink the product infusion stand in parts and to go new ways in construction and material. Here, too, the project has pointed out lines to pursue.

From a technical point of view, the main open issues in this project are "braking" and "hygiene". The topic of braking cannot be conclusively dealt with due to a very heterogeneous

requirements profile. In addition, the final technical prototype changes the possible uses and application scenarios of the infusion stand on which the requirements are based to such an extent that it is necessary to reassess the requirements under new conditions. Due to time constraints, this could no longer be solved within this project. The topic of hygiene, such as cleaning and disinfection, especially of the wheels, but also of the entire technical system, presented itself to the project team as extremely complex - both from a technical and a health science perspective. Discussions with clinical users and specialised industrial companies revealed that there are many possible approaches, but that they must be approached holistically, interdisciplinarily and systematically. Unfortunately, this justified requirement clearly exceeds the scope of this project, so that it has to be put into perspective as a very important future project topic. Most of the technical development results of this project can be applied or adapted to other aids. The knowledge gained about the chassis, castors and wheels, connecting elements and suspensions can be used in varying proportions to improve other common aids that also need to be revised, such as rollators, shower toilet chairs or hospital beds.

As with the infusion stand, the design and construction of these aids has hardly changed over the decades. Although technically possible and sensible, there is hardly any choice and variation options for adapting to personal needs, e.g. in terms of frame height, arrangement and number of wheels, seat or even handles. There is great potential to transfer the technical results from this project to the user-centred revision of the other aids mentioned.

With this research project, we would like to set an impulse for the participatory involvement of users in assistive technology research. The user groups can participate in various phases of product development; at the very least, however, the products should be regularly evaluated in their use by the users. This could also be done in connection with the purchase of new infusion stands. The review of infusion stands from various (international) companies shows that there are indeed infusion stand models that are more likely to meet the respective requirements. Unfortunately, the user groups are rarely involved in the purchase or ordering of the aids; patients are probably only involved if they buy the products themselves - which is not to be expected in the case of the infusion stand. However, the selection of the respective

products can only be supported if the user groups are involved in the selection process at an early stage and the participants jointly obtain an overview of the market.

Within the framework of this research project, the disciplines of Mechanical Engineering and Nursing Science worked closely together. From our point of view, it makes a lot of sense to set up such a development project in an interdisciplinary way. It has been shown that although the methodological and methodological approaches are sometimes different, both disciplines follow a strong evidence-based approach and apply comparable scientific principles.
However, the interdisciplinarity successfully implemented in the project is also costly for all involved: it is not only necessary to communicate and exchange views sufficiently, but also to adapt in mindset and methodology on both sides in order to achieve truly successful results. All too often, technology development is confronted with conflicting product requirements that can only be met profitably for users in an intensive technology-care dialogue. Against this background, from a technical point of view, the agile procedure, adapted from "Scrum", has proved to be an ideal structural framework. From our point of view, it can make sense to apply this procedure in a targeted manner for further developments in the field of tools.

5 Long-term added value of the project and the results for practice

The interdisciplinary examination of the "infusion stand" aid within this project marks a milestone for the collaboration between Prof. Meinecke and Prof. Elsbernd. They form an interdisciplinary research team that combines the two disciplines of mechanical engineering and nursing science to address issues around technology and nursing. In doing so, they pay special attention to (technical) nursing aids, some of which have an enormous technical development backlog. The project has further developed the conventional infusion stand and developed a prototype that meets today's demands for safety, data protection, design and other aspects. Nationally and internationally, there are hardly any further developments worth mentioning, so that this project has a high innovative power. The project is excellently integrated into the research focus of the Esslingen University of Applied Sciences "Society in Transition", an area to which Prof. Meinecke's endowed professorship has also been dedicated. Research into technical aids in care is a special area here, which in our view can only be researched in an interdisciplinary way, as has happened in this project. The project and the

results will have a clear signal effect for the necessity of special interdisciplinary research, as well as for the infusion stand itself.

6. Formats of interaction

Against the backdrop of the Corona pandemic, new interactive formats had to be developed to engage with the identified target groups. Thus, the first two focus groups with carers had to be held online via the programme "Webex". Here, the advantage of being able to record the meeting in picture and sound (after consent) became apparent, which greatly simplified the later data analysis. Limitations and restrictions were technical problems on the part of the users (picture or / and sound did not work) and the lack of possibility to carry out adequate product testing (no hands-on possibility). Later meetings took place under strict hygiene conditions in presence, which significantly strengthened the cooperation and produced excellent results.

The project team worked with each other and with various cooperation partners mainly in digital format. Modern media and programmes that also support creative techniques provided support as well, which was very beneficial in this project. The technical development work could take place under strict hygienic conditions, mostly in presence in the laboratory, which was very important for the discussions.

7. Exploitation of project results, knowledge and technology transfer

In the short term, it makes sense to further develop the existing infusion stand models in an evolutionary way in order to quickly improve the functions and mitigate the greatest weaknesses. In this respect, the project team has shown in the context of technical developments that there are very simple, but in terms of functionality, safety and data protection very worthwhile adaptations that can and should be taken up by the industry. The redesign of the basic element alone brings so much improvement for the use of this aid that an industrialisation in several senses - for the individual and society - would be more than promising. Another revolutionary development is also to be initiated by the project. It is certainly promising to rethink the product infusion stand in parts and to break new ground in construction and material. Here, too, the project has pointed the way. Most of the technical development results of this project can be applied or adapted to other aids. The knowledge gained about the chassis, castors and wheels, connecting elements and suspensions can be

used in varying proportions to improve other common aids that are just as much in need of revision, such as rollators, shower commode chairs or hospital beds. As with the infusion stand, the design and construction of these aids have hardly changed over the decades. Although technically possible and appropriate, there is hardly any choice and variation possibilities for adaptation to personal needs, e.g. with regard to the frame height, the arrangement and number of wheels, the seat or even the handles. Here, there is great potential for transferring the technical results from this project to the user-centred revision of the other aids mentioned above.

By the publications in the professional journals and the contacts established within the project, a clear increase in awareness of the topic of "infusion stands" and its challenges for the user groups can be observed. This is to be further strengthened in the future by additional publications.

Finally, the project group would like to express its gratitude to the funding body. There are not many formats that make this absolutely necessary interdisciplinary research and collaboration possible. However, in our view, this joint, interdisciplinary work is essential for the topics addressed in the research focus and, as happened in this project, also extremely successful.

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