9 Simulator Evaluation

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Take-Home Messages

- Simulator evaluation is dependent on the wishes of the community (Chap. 2), the general requirements for medical simulators and validation (Chap. 8).
- Simulator validation is a precondition that ensures useful and appropriate skills training.
- Higher-quality studies are still required to show the validity of most simulators.
- Standardisation of validation protocols and training tasks would allow objective comparison between different simulators.
- At present, the most validated simulators are Procedicus™ virtual reality shoulder joint and the Sawbones™ anatomic knee bench model.

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9.1 Requirements for Simulator Evaluation

Validation is a very important, but not the sole criterion based upon which simulators should be evaluated. In this chapter, we propose three sets of evaluation criteria to assess the appropriateness of simulators to train arthroscopic skills: wishes from the arthroscopic community (Chap. 2), general requirements for medical simulators and validation (Chap. 8). The first two sets of criteria are elucidated in the remainder of this section; the latter is fully covered in Chap. 8. *For the simulators presented in* Chaps. 5, 6, and 7, we evaluate to what extent they fulfil these three sets of criteria. This will be done using a 3-point Likert scale: + implies the simulator completely fulfils a requirement, ~ implies that the simulator fulfils a requirement to some extent and – implies that the simulator does not fulfil a requirement. Whenever possible, the evaluation is performed per type of simulator, for example, high-fidelity virtual reality simulators or box trainers (see classification Chap. 6).

9.2 Wishes from the Arthroscopy Community

In Chap. 2, an inventory held amongst the ESSKA members is presented indicating the necessary tasks and skills that should be trained in a simulated environment away from the patient, before training in the operating room continues. As was shown, some of

M. Karahan et al. (eds.), *Effective Training of Arthroscopic Skills*,
DOI 10.1007/978-3-662-44943-1_9, © ESSKA 2015

the skills do not require actual instrument handling (e.g. knowledge on anatomy) or a simulator per se (e.g. patient positioning). These skills are omitted in this chapter, which solely focuses on the arthroscopic skills training that do require a simulator. Therefore, we propose to evaluate the different types of simulators on their appropriateness to enable training of the following top five specific skills:

1. Precise portal placement
2. Triangulating the tip of the probe with a 30° scope
3. Insertion of the arthroscope
4. Entry of all compartments (medial/lateral/posteromedial, suprapatellar/intercondylar)
5. Identification of all relevant structures in the knee joint (medial compartment, intercondylar notch, lateral compartment, lateral gutter, medial gutter)

9.3 General Requirements for Medical Simulators

The potential of arthroscopic simulators to be or become a valuable training modality also depends on them fulfilling the general requirements for medical simulators. These requirements are based on an extensive literature review by Issenberg and co-workers (Issenberg et al. 2005) that was updated by McGaghie and co-workers (McGaghie et al. 2010). This list of ten items is presented in order of importance:

Providing feedback
Repetitive practice
Curriculum integration[1]
Range of difficulty level
Multiple learning strategies (see additional information Chaps. 3 and 4)
Capture clinical variation
Controlled environment
Individualised learning
Defined outcomes
Simulator validity[2]

9.4 Evaluation of Wishes and General Requirements

Analysis of Table 9.1 indicates that none of the available simulators offers the capability to train the top five of required arthroscopic skills that a resident should possess before continuing their training in the operating room. Only the anatomic bench models with replaceable skins allow training of precise portal placing. Care has to be taken that each trainee needs to palpate the knee before creating their own set of portals. Of course, when training on cadaver knee joints, the first trainee that starts also has the opportunity to create a set of portals, but those following do not. As box trainers do not represent a realistic knee joint environment, they only train triangulation skills. This is the main arthroscopic skill that can be practiced on all simulators. Triangulation is a core arthroscopic skill, and it is important to practice, since the required eye–hand coordination is different from eye–hand coordination used in daily life. Additionally, all training systems that offer a human joint environment to train in allow training of the entry to compartments and identification of anatomic structures (Table 9.1). A challenge of virtual reality simulators is offering the realistic haptic feedback, especially in tasks such as the insertion of arthroscope. To increase realism of haptic sensation, high-fidelity virtual simulators now have a passive physical model of the joint (McCarthy et al. 2006; Moody et al. 2008).

As cadavers differ per sample, they do not offer a truly controlled environment where repetition of exercises can be practiced over and over (Table 9.2).

[1] We have interpreted this requirement as the simulator offering a high usability that is being ‘user friendly’, which implies that no manual is required to handle the simulator, and ‘easy to use’, which implies that no preparation time is required to start training.

[2] As indicated, simulator validation will be discussed in a separate section, where the literature has been reported most extensively on this requirement.

Table 9.1 Crosstab within the left column the top five arthroscopic skills that need to be trained prior to start training in the operating room and in the top row different types of training systems

Skill	Cadaver	Box trainers	Anatomic bench models	VR simulators
Precise portal placement	~	–	+	–
Triangulating the tip of the probe with a 30° scope	+	+	+	+
Insertion of the arthroscope	+	–	+	–
Entry of all compartments (medal/lateral/posteromedial, suprapatellar/intercondylar)	+	–	+	+
Identification of all relevant structures in the knee joint (medial compartment, intercondylar notch, lateral compartment, lateral gutter, medial gutter)	+	–	+	+

Table 9.2 Crosstab within the left column the nine general requirements for simulator design and in the top row different types of simulators

General requirement	Cadaver	Box trainers	Anatomic bench models	VR simulators
Providing feedback	~	~	~	+
Repetitive practice	~	+	+	+
Curriculum integration	–	+	+	+
Range of difficulty level	~	–	~	+
Multiple learning strategies	–	~	~	~
Capture clinical variation	~	–	~	~
Controlled environment	–	+	+	+
Individualised learning	+	+	+	+
Defined outcomes	+	+	+	+

Additionally, the level of difficulty or availability of clinical variation cannot be preset per cadaver. When training on multiple cadavers, of course natural variation is available in size and anatomic structures but is more difficult to simulate different pathologies. In many countries, legislation is restrictive and prevents easy access to cadaver specimens, and if procured the cost of these specimens can be extremely high. Finally, cadavers require considerable preparation, especially when sensors are added to register training performance with defined outcomes and to offer feedback, objectively. Therefore, this type of training environment is less suitable for curriculum integration where training on a frequent repetitive basis is required. However, it can be very useful for advanced arthroscopists who are learning or developing new techniques or preparing for a rare but complex operation.

Box trainers are by definition low-fidelity trainers, which immediately indicates their limitation in offering different difficulty levels and clinical variation (Table 9.2). Their strengths are that they offer endless repetition in a highly controlled environment, which is convenient for novice residents as they truly focus on the basics and are allowed to make as many mistakes as needed. Provision of feedback can be offered by adding sensors in the box to register training performance with defined outcome measures.

Both anatomic bench models and virtual reality simulators possess all the general simulator requirements to a certain extent (Table 9.2). Anatomic bench models represent human joints. Some companies offer knee joints in different sizes and in a left and right version (Chap. 6), but similar to cadavers, this is not truly offering clinical variation in one model. The level of difficulty based on joint geometry cannot be changed, and most feedback that is given by residents indicates that the intra-articular joint space is unrealistically large, which compromises training when trainees have established basic arthroscopic skills proficiency. Some anatomic bench models do offer the possibility to simulate a bleeding, which increases complexity. Additionally, lots of different meniscal tears are usually available for training.

Again sensors can be added to the system to register performance. However, for all three training environments (cadavers, box trainers and anatomic bench models), it is noted that solely providing sensors is insufficient to offer supervisor-independent learning, as novices need to be guided in each step.

This latter aspect is the strength of virtual reality simulators. As these simulators are inherently computer based, they offer intuitive use of pictures, movies and other multimedia tools to support autonomous learning when using a simulator (Hurmusiadis et al. 2011; Megali et al. 2005). Additionally, as mathematical calculations are necessary anyhow to represent the virtual environment, metrics such as task time, path length and the number of unallowed tissue collisions can be easily documented and used for feedback and training progression. Finally, the level of clinical variation in the sense of different pathologies that can be trained is often abundant, but again most virtual reality simulators use only one knee configuration to train in.

9.5 Validation

Validation studies of the simulators are described in Chaps. 6 and 7 by searching literature databases (Pubmed and Scopus) using the following keywords: simulator name, 'arthroscopic simulator' and validity. Several authors recently have presented quite elegant overviews of the current status of arthroscopic simulators, and in this section we will follow their work (Frank et al. 2014; Modi et al. 2010; Slade Shantz et al. 2014). The definitions of the different types of validity are described in Chap. 8.

9.5.1 Learning Curve

Learning curves are determined to demonstrate that there is training progression of the trainee (Table 9.3). The possibility of repetitive training is ranked in the top 10 of simulator requirements (Table 9.2) (Issenberg et al. 2005). All simulator environments qualify this requirement accept cadaver material. Howells and co-workers (Howells et al. 2009) clearly show the need for repetitive training. Unfortunately, repetitive performance of a task on a simulator does not indicate that the correct skills are trained. That is why testing of other types of validity is required, as we all know that having to relearn skills after incorrect training is harder than learning new skills.

9.5.2 Face Validity

Table 9.4 presents all studies that have tested the face validity of various simulators. Four out of the six are virtual reality simulators. Face validity testing is relatively easy to achieve as it merely requires a questionnaire and a group of experts indicating their opinion on the 'looks' of the simulator (e.g. Appendix 9.A). Despite this, it is not the most evaluated type of validity. This might be

Table 9.3 The learning curves as assessed after repeated training on various systems

Simulator	Type	Joint	Study
Procedicus™	VR simulator	Knee	Bliss et al. (2005)
Procedicus™	VR simulator	Shoulder	Gomoll et al. (2008)
SKATS	VR simulator	Knee	McCarthy et al. (2006), Moody et al. (2008)
Sawbones™	Anatomic bench model	Knee	Howells et al. (2008b), Jackson et al. (2012)
Sawbones™	Anatomic bench model	Shoulder	Howells et al. (2009)
Sawbones™	Anatomic bench model	Hip	Pollard et al. (2012)
Knee Arthroscopy Simulator	Anatomic bench model	Knee	Escoto et al. (2013)

Only papers are included that explicitly indicate the presence of a learning curve

Table 9.4 Inventory of all simulators that were tested for face validity

Simulator	Type	Joint	Study
SKATS	VR simulator	Knee	McCarthy and Hollands (1998), McCarthy et al. (2006), Moody et al. (2008)
Procedicus™	VR simulator	Shoulder	Srivastava et al. (2004)
Arthro Mentor™ (InsightArthroVR1)	VR simulator	Knee	Bayona et al. (2008), Tuijthof et al. (2011)
PASSPORT	Anatomic bench model	Knee	Tuijthof et al. (2010a), Tuijthof et al. (2012)
ArthroStim™	VR simulator	Knee	Tuijthof et al. (2011)
Knee Arthroscopy Simulator	Anatomic bench model	Knee	Escoto et al. (2013)

Only papers are included that explicitly indicate evaluation of face validity

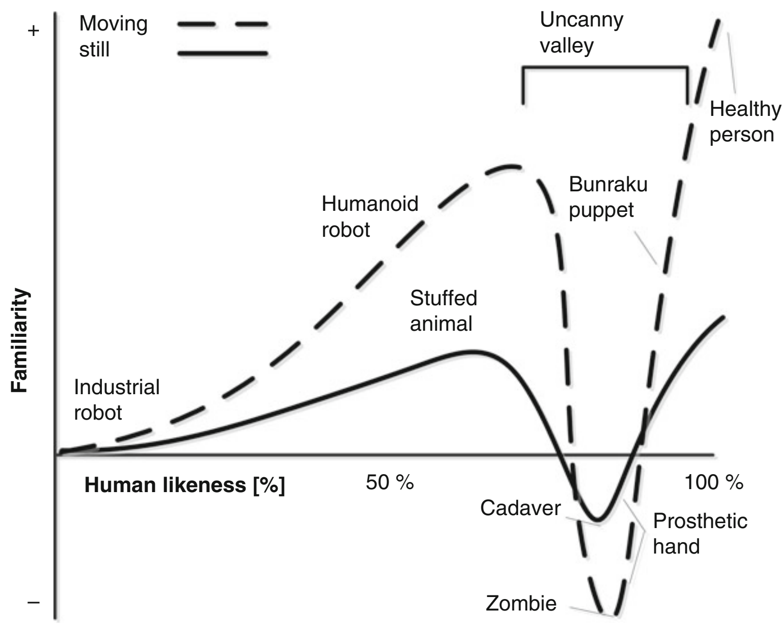

Fig. 9.1 Graphical illustration of the nonlinear relationship between the experience of negative and positive affect and perceived human likeness. The uncanny valley indicates the negative perceived realism even though the human-like object is highly realistic (Cheetham and Jancke 2013)

caused by the fact that simulator companies team up with a few experts surgeons when developing their systems and use those expert opinions to verify sufficient face validity. From a scientific point of view, questioning a larger panel of experts who are not directly involved in the development would provide stronger evidence.

Two other aspects need to be discussed regarding assessment of face validity. The first is the so-called *uncanny valley* effect (Cheetham and Jancke 2013; MacDorman 2005). The 'uncanny valley' hypothesis proposes that the perception of human-like characters such as robots or computer-generated avatars can evoke negative or positive affect depending on the object's degree of visual and behavioural realism along a dimension of human likeness (Fig. 9.1).

Although arthroscopic simulators are not human-like robots, they aim to represent part of the human. Even though we cannot provide scientific evidence, we noticed during our face validity tests that participants tend to become stricter in their judgment regarding the realism of a simulator, if that simulator has a high degree of realism. Contrary, the participants were more forgiving regarding simulators that clearly present a less realistic simulation of the human joint. Also, it should be taken into account that with current development in graphics of computer games, participants also increase their standards

Table 9.5 Inventory of all simulators that were tested for content validity

Simulator	Type	Joint	Study
Navigation Training Module	VR simulator	Knee	Megali et al. (2002), Megali et al. (2005)
Sawbones™	Anatomic bench model	Shoulder	Ceponis et al. (2007)
Arthro Mentor™ (InsightArthroVR1)	VR simulator	Knee	Bayona et al. (2008)

Only papers are included that explicitly indicate evaluation of content validity

regarding virtual reality simulation, as they know what could be possible. This suggests that the face validity judgment scale is nonlinear.

The second aspect that should be taken into account when interpreting face validity studies is the required realism of a simulator for the intended training purpose. This is nicely illustrated by Buzink and co-workers (Buzink et al. 2010) who showed that certain basic skills might be more efficiently trained in a truly abstract environment (such as a box trainer) than in an *almost realistic* virtual reality environment of a body part.

9.5.3 Content Validity

Table 9.5 presents all studies that have tested the content validity of various simulators. Noticeable are the short list of simulators and the fact that one of those is an anatomic bench model, which by itself has no means displaying the task to be trained. Two trends can be distinguished regarding the absence of numerous content validity testing presented in literature. Firstly, companies either develop tasks or exercises in close collaboration with a small group of experts or leave it to the ones that purchase their products to design their own tasks. Secondly, researchers who develop new concepts for simulated environments focus usually on one navigation task to indicate the proper performance of their system. In all, this properly reflects the fact that the execution of arthroscopic procedures can be performed in various ways. Therefore, this approach is suitable for informative training. However, if the future perspective is that summative training tests are going to be performed to demonstrate proficiency levels, it is highly recommended that the arthroscopic community develops a set of validated tasks that can be used. This is not a trivial task, as it requires the decomposition of tasks into core steps. For expert surgeons that are so used to performing arthroscopy as, for example, riding a bike or tying shoe laces, it can be difficult to describe what they do and to distinguish between the various sequential actions.

9.5.4 Construct Validity

Table 9.6 presents all studies that have tested the construct validity of various simulators. Construct validity has been tested most extensively for both anatomic bench models and virtual reality simulators. All studies confirm construct validity between novices and experts, and this has been nicely presented by Slade Shantz and co-workers (2014).

Slade Shantz et al. 2014 in their recent systematic review. However, some critical remarks should be made (Modi et al. 2010; Slade Shantz et al. 2014): usually only one task is used (e.g. navigation and probe task), groups are small, levels of expertise are differently defined, and no evidence was found between intermediate and expert or novice groups. The latter could be explained by the fact that the intermediate group is the most heterogeneous group, and their motivation is possibly lowest (Srivastava et al. 2004; Tuijthof et al. 2011).

9.5.5 Concurrent Validity

Table 9.7 presents all studies that have tested the concurrent validity of various simulators. Concurrent validity is indirectly related to the performance of a simulator, as it concerns

Table 9.6 Inventory of all simulators that were tested for construct validity

Simulator	Type	Joint	Study
Procedicus™	VR simulator	Shoulder	Smith et al. (1999), Pedowitz et al. (2002), Srivastava et al. (2004), Gomoll et al. (2007), Gomoll et al. (2008)
VE-KATS	VR simulator	Knee	(Sherman et al. 2001)
SKATS	VR simulator	Knee	McCarthy et al. (2006), Moody et al. (2008)
Arthro Mentor™ (InsightArthroVR1)	VR simulator	Knee	Bayona et al. (2008), Tuijthof et al. (2011)
Arthro Mentor™ (InsightArthroVR1)	VR simulator	Shoulder	Andersen et al. (2011), Martin et al. (2012)
Sawbones™	Anatomic bench model	Shoulder	Howells et al. (2008a)
Sawbones™	Anatomic bench model	Knee	Tashiro et al. (2009)
PASSPORT	Anatomic bench model	Knee	Tuijthof et al. (2010a), Tuijthof et al. (2012)
Simendo Arthroscopy™	VR simulator	Knee	Tuijthof et al. (2010b)
ArthroStim™	VR simulator	Knee	Tuijthof et al. (2011), Cannon et al. (2014)
Human	Cadaver	Knee	Olson et al. (2013)

Only papers are included that explicitly indicate evaluation of construct validity

Table 9.7 Inventory of all simulators that were tested for concurrent validity

Simulator	Type	Joint	Study
Procedicus™	VR simulator	Shoulder	Smith et al. (1999), Pedowitz et al. (2002), Srivastava et al. (2004), Gomoll et al. (2007), Gomoll et al. (2008)
SKATS	VR simulator	Knee	McCarthy et al. (2006), Moody et al. (2008)
Sawbones™	Anatomic bench model	Shoulder	Howells et al. (2008a)
Sawbones™	Anatomic bench model	Knee	Tashiro et al. (2009)
Arthro Mentor™ (InsightArthroVR1)	VR simulator	Shoulder	Andersen et al. (2011)

Only papers are included that explicitly indicate evaluation of concurrent validity

the type of metrics that are used to indicate trainee performance. The studies that do measure multiple metrics usually track the task time, the path length and number of tissue collisions, which demonstrate a high correlation. In Chap. 11, many more potential metrics are described that could contribute to an overall performance profile of a trainee by combining efficiency and safety metrics.

9.5.6 Predictive or Transfer Validity

Table 9.8 presents all studies that have tested the predictive or transfer validity of various simulators. Predictive and transfer validity provide the most highest level of validity by indicating that training of the simulated task transfers to actual performance in the operating room (Chap. 8). All but one of the studies presented in Table 9.8 present transfer validity to cadaver training, which is considered the preferred training modality of the surgeons (Chap. 2) (Safir et al. 2008; Vitale et al. 2007). Moody and co-workers studied transfer validity from one version of their SKAT simulator to an upgraded version in which passive haptic feedback was included (Moody et al. 2008). Only the study by Howells and co-workers (Howells et al. 2008b) demonstrates transfer validity to actual performance in the operating room. For their study, they used an anatomic bench model added with registration devices, which as demonstrated by them indicates a viable way of training.

Table 9.8 Inventory of all simulators that were tested for predictive or transfer validity

Validity	Simulator	Type	Joint	Study
Predictive	SKATS	VR simulator	Knee	McCarthy et al. (2006)
Transfer	SKATS	VR simulator	Knee	Moody et al. (2008)
Transfer	Sawbones™	Anatomic bench model	Knee	Howells et al. (2008b), Butler et al. (2013)
Transfer	Arthro Mentor™ (InsightArthroVR1)	VR simulator	Shoulder	Martin et al. (2011)
Transfer	Procedicus™	VR simulator	Shoulder	Henn III et al. (2013)

Only papers are included that explicitly indicate evaluation of predictive or transfer validity

9.6 Case Example Standardised Study Protocol

Modi and co-workers (Modi et al. 2010) indicated a range of limitations on the methodology used in evaluation studies of simulators: the use of poorly validated outcome measures, the absence of multiple centre studies and the impossibility of comparing groups or simulators. In an effort to overcome a number of these limitations, we have set up a general study protocol to assess face and construct validity of any type of arthroscopic simulators (Tuijthof et al. 2011). This protocol enables evaluation and relative comparison of any type of simulator (virtual reality or phantom). We have evaluated ArthroStim*™* (Touch of Life Technologies, Aurora, CO, USA: Simulator A), Arthro Mentor™ (Simbionix, Cleveland, Ohio, USA, previously known as the InsightArthroVR1 Arthroscopy Simulator (GMV, Madrid, Spain): Simulator B), VirtaMed ArthroS™ (VirtaMed AG, Zurich, Switzerland: Simulator D) and our own development the PASSPORT simulator (Delft University of Technology and Academic Medical Centre, The Netherlands: Simulator C). In short the protocol is set up as follows.

Participants were recruited and grouped in different experience levels. Only the results are presented of novices who had never performed an arthroscopic procedure and experts who had performed more than 60 arthroscopies. The level of 60 was set using a study by O'Neill and co-workers (O'Neill et al. 2002) who questioned a large group of fellow ship directors who indicated a mean of 62 arthroscopies to be performed in other to achieve proficiency. Between 6 and 11 participants were present in each experience group for each simulator. All participants were scheduled a maximum period of 30 min in order to be able to recruit experts.

Face validity, educational value and user-friendliness of the simulators were determined by the participants performing up to three exercise(s) that were characteristic for that particular simulator. Clear instructions were given that performance of these exercises would not be documented, and the researcher pointed explicitly to manner in which performance feedback was given to the participant. Afterwards the participants were asked to fill out a questionnaire (Appendix 9.A) (Tuijthof et al. 2011). Questions were answered using a 10-point numerical rating scale (NRS) (e.g. 0 = completely unrealistic and 10 = completely realistic). Only the answers of the intermediates and experts regarding face validity and educational value were included. A value of 7 or greater was considered as being satisfactory. Face validity of the outer appearance was demonstrated for all simulators, but only simulator C demonstrated face validity for intra-articular joint realism and instrument realism (Fig. 9.2). This result was significantly different from simulator B for intra-articular joint realism and significantly different from all simulators for instrument realism ($p < 0.05$). The explanation is that simulator C is the only system that uses real instruments and a knee bench-top model to mimic sense of touch, which was considered

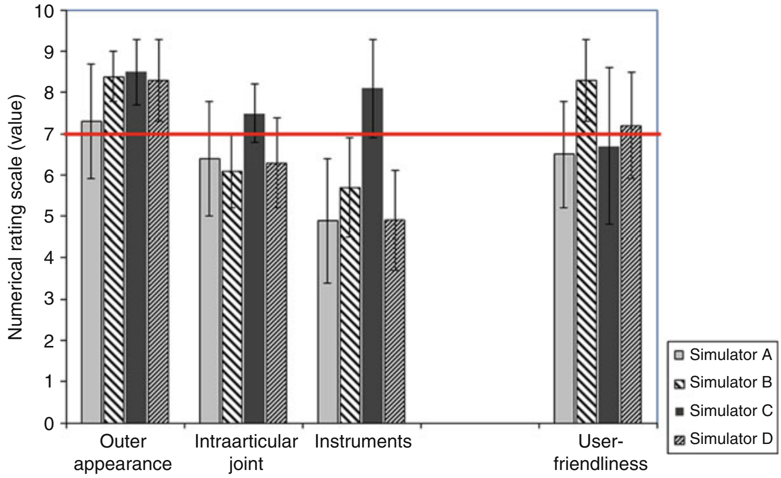

Fig. 9.2 Face validity and user-friendliness of four simulators

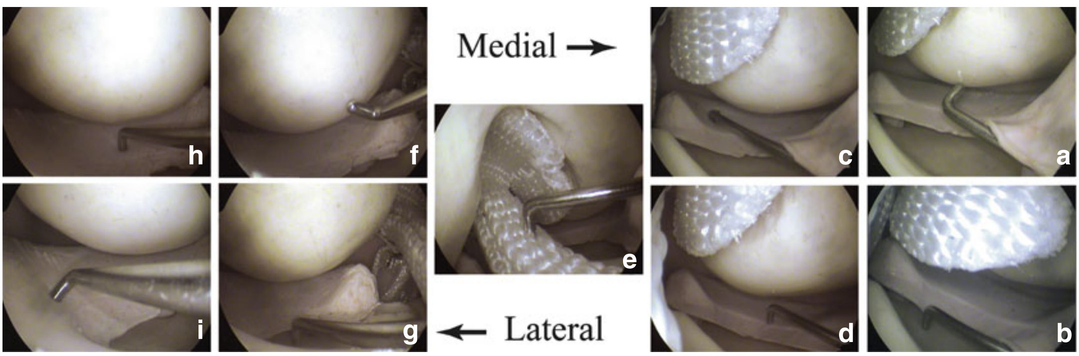

Fig. 9.3 Pictures of the intra-articular joint space of simulator C. The landmarks had to be probed in the following sequence for the navigation task: (**a**) medial femoral condyle, (**b**) medial tibial plateau, (**c**) posterior horn of medial meniscus, (**d**) midsection of medial meniscus, (**e**) anterior cruciate ligament, (**f**) lateral femoral condyle, (**g**) lateral tibial plateau, (**h**) posterior horn of lateral meniscus and (**i**) midsection of lateral meniscus (© GJM Tuijthof, 2014. Reprinted with permission)

the biggest asset by the participants. Simulators B and D demonstrate good user-friendliness, with the difference between simulators A and B being significant ($p<0.05$). All virtual reality simulators needed improvement of the sense of touch. All simulators could benefit from more realistic structures but were considered as valuable training tool in the beginning of the residency curriculum.

Construct validity was assessed based on a single predefined navigation task. Nine anatomic landmarks had to be probed sequentially: medial femoral condyle, medial tibial plateau, posterior horn of the medial meniscus, midsection of the medial meniscus, ACL, lateral femoral condyle, lateral tibial plateau, posterior horn of the lateral meniscus and midsection of the lateral meniscus (Fig. 9.3) (Tuijthof et al. 2010a). The task trial times were recorded by separate digital video recording equipment to guarantee uniformity in data processing. All participants performed the navigation task 5 times. Construct validity was determined with the Kruskal–Wallis test by calculation of overall significant differences in task time between the three groups for each of the five task trials.

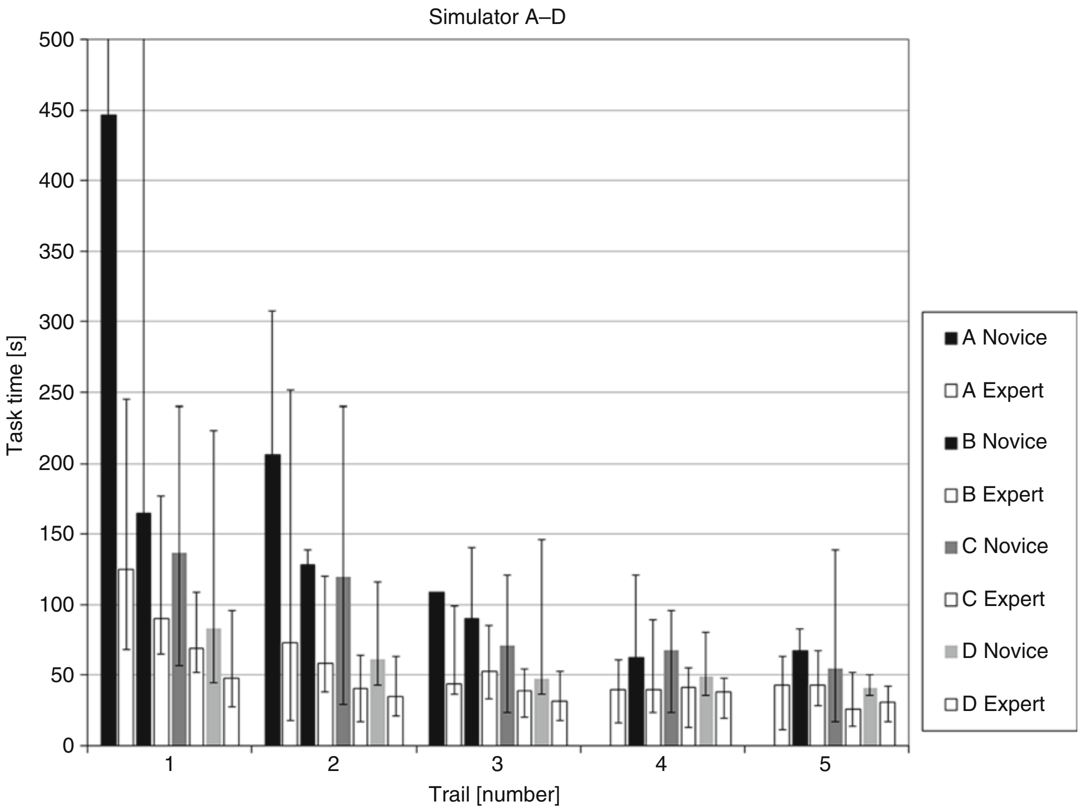

Fig. 9.4 Construct validity of four simulators

The significance level was adjusted for multiple comparisons with the Bonferroni–Holm procedure (alpha = 0.05) (Holm 1979). Mann–Whitney U tests were used for pair-wise comparisons to highlight significant differences. Construct validity was shown for simulators C and D, as the novices were significantly slower than the experts in completing all five trials (Fig. 9.4). For simulator A, only 2 out of 11 novices could complete all task trials within the set time limit. This indicates a clear distinction between novices and experts, which unfortunately cannot be supported by actual measurements. Simulator B partly demonstrated construct validity as the experts were faster in the second and third trials compared to the novices.

As the same navigation and probe task were performed on all simulators, it allows comparison of the performance of the experts. All expert task times of trial 5 are in the same range, and do not significantly differ. This suggests that for the evaluated navigation task, training on any of the simulators yields the same performance results. A noticeable distinction between the learning curves of the experts is that simulator A shows a steep learning curve with trial 1 being significantly slower than trial 5, while simulator D shows no significant difference between trials 1 and 5.

This might suggest that the virtual reality environment of simulator D is the most realistic as experts do not have to become acquainted with the simulator.

9.7 Discussion

Analysing the wishes from the arthroscopic community, the conclusion is that triangulating the tip of the probe with a 30° scope, entry of all compartments and identification of all relevant structures in the knee joint can be trained with currently available arthroscopic simulators (Table 9.1). Precise portal placement and adequate insertion of the arthroscope cannot be trained. As indicated in Chap. 6, efforts are being made to enhance skin realism and allow repetitive training of portal placement.

Analysing the general requirements regarding simulator design, both anatomic bench models and virtual reality simulators possess all general simulator requirements to a certain extent (Table 9.2). They therefore appear to be most suitable for integration in a training curriculum. Notice that for objective performance tracking and autonomous training, anatomic bench models need to be complemented with registration devices and multimedia tools. On the other hand, virtual reality simulators need improvement regarding haptic feedback (Moody et al. 2008; Tuijthof et al. 2010a; Zivanovic et al. 2003). Both box trainers and cadaver training have limitations, which makes them more suitable for training in a distinct part of the entire training process: at the very beginning of the learning curve (box trainers) and at the end of the learning curve, where experienced arthroscopists want to learn a new technique or a difficult procedure (cadaver material).

Validation tests have been performed by the pioneers in the late 1990s and early zeros. They developed virtual reality simulators by applying new computer science techniques or used conventional anatomic bench model to demonstrate effect of training outside the operating room (Bliss et al. 2005; McCarthy and Hollands 1998; Megali et al. 2002; Pedowitz et al. 2002; Sherman et al. 2001; Smith et al. 1999; Srivastava et al. 2004). It is worth noting that it was simulators of the knee and shoulder joint that were evaluated. Unfortunately some of the simulators that have been quite extensively validated (Procedicus™ shoulder joint) are no longer commercially available or have never been further developed into a commercial product (SKATS and PASSPORT knee joint simulators) (Tables 9.3, 9.4, 9.5, 9.6, 9.7, and 9.8). However, including those simulators in this chapter helps provide a strong indication that, similarly in other endoscopic fields, arthroscopic simulators demonstrate face and construct validity (Slade Shantz et al. 2014) and to some extent content, concurrent and transfer validity. Additionally, training in a simulated environment correlates to improved skill (Frank et al. 2014; Modi et al. 2010), which ultimately should increase patient safety and efficiency in training time.

There is however still scope for improving validation studies as stated by Modi and coworkers (Modi et al. 2010): the use of validated outcome measures, multiple centre studies, study designs that allow group and simulator comparison and assessment of transfer validity are all areas that still need research and development.

Appendix 9.A Questionnaire Face Validity and Usability

The questionnaire will remain anonymous! Please fill in all the questions by encircling one number ranging from 0 to 10, much as you would score an exam. Encircling *N/A* if the question does not apply to you. Encircling one of the options that applies to you and filling in the boxes if needed.

General questions

What is your age?

What is your gender?

Male	**Female**

How many arthroscopic surgeries of the knee did you perform?

0*	**1 - 59**	**> 60**

*If answered 0, how many arthroscopic surgeries have you witnessed last year?

Did you previously have arthroscopy training sessions with one or more of the following modalities? *(more than one option is allowed)*

No	**cadaveric material**	**virtual reality simulator***	**physical phantom***

*Please specify product name:

Do you have experience in playing computer games?

Yes*	**No**

*If answered yes, please specify the hours per week and for how many years:

Hours per week	**Years**

Questions regarding the simulator before evaluation test

What is your opinion on the outer appearance of <u>any</u> simulator?

Not important, the intra-articular anatomy is what matters	Important, the joint should be directly recognizable on the outside

What is your opinion on the outer appearance of <u>this</u> simulator?

Completely unrealistic	0	1	2	3	4	5	6	7	8	9	10	**Completely realistic**

Is it clear in which joint you will be operating?

Completely unclear	0	1	2	3	4	5	6	7	8	9	10	**Completely clear**

Questions regarding the simulator after evaluation test

Questions concerning the realism of the simulator

The not applicable (N/A) option is only allowed if you have not performed any arthroscopic operations or have seen less than 5 arthroscopic operations.

Is it clear which portals are being used? N/A

Completely unclear	0	1	2	3	4	5	6	7	8	9	10	**Completely clear**

How realistic is the intra-articular anatomy? N/A

Completely unrealistic	0	1	2	3	4	5	6	7	8	9	10	**Completely realistic**

Are all essential anatomic structures present?

Yes	**No***	**N/A**

***If answered with no, which structure(s) do you miss?**

How realistic is the texture of the structures? N/A

Completely unrealistic	0	1	2	3	4	5	6	7	8	9	10	**Completely realistic**

How realistic is the color of the structures? N/A

Completely unrealistic	0	1	2	3	4	5	6	7	8	9	10	**Completely realistic**

How realistic is the size of the structures? N/A

Completely unrealistic	0	1	2	3	4	5	6	7	8	9	10	**Completely realistic**

How realistic is the size of the intra-articular joint space? N/A

Completely unrealistic	0	1	2	3	4	5	6	7	8	9	10	**Completely realistic**

How realistic is the arthroscopic image itself? N/A

Completely unrealistic	0	1	2	3	4	5	6	7	8	9	10	**Completely realistic**

Questions concerning the instruments

Is it clear what instruments you are using?

Yes	**No**	**N/A**

How realistic do the instruments look? N/A

Completely unrealistic	0	1	2	3	4	5	6	7	8	9	10	**Completely realistic**

How realistic is the motion of your instruments? N/A

Completely unrealistic	0	1	2	3	4	5	6	7	8	9	10	**Completely realistic**

Is there any delay between the movements you make and those projected on-screen?

Yes	**No**	**N/A**

How realistic does the tissue feel when you are probing? N/A

Completely unrealistic	0	1	2	3	4	5	6	7	8	9	10	**Completely realistic**

How realistic does the tissue feel when you are cutting? N/A

Completely unrealistic	0	1	2	3	4	5	6	7	8	9	10	**Completely realistic**

Questions concerning usage

How clear are the instructions to start an exercise on the simulator?

Complete-ly unclear	0	1	2	3	4	5	6	7	8	9	10	**Com-pletely clear**

Did you feel the need to read a manual before operating the simulator?

Yes	**No**

How do you feel about the variation in exercises offered by the simulator?

Too little	**Adequate**	**Too much**

How do you feel about the difference in required skill level between exercises?

Too little	**Adequate**	**Too much**

If the virtual reality environment does not represent a joint, are the exercises still suitable to train arthroscopic skills?

Yes	**No**	**N/A**

Does the simulator allow training of joint inspection?

Yes	**No**

Does the simulator allow training of joint irrigation?

Yes	**No**

Does the simulator allow therapeutic interventions?

Yes	**No**

How clear is the presentation of your performance by the simulator?

Complete-ly unreal-istic	0	1	2	3	4	5	6	7	8	9	10	**Com-pletely realistic**

Is it clear how you can improve your performance?

Complete-ly unreal-istic	0	1	2	3	4	5	6	7	8	9	10	**Com-pletely realistic**

How motivating is the way the results are presented to improve your performance?

Most de-motivat-ing	0	1	2	3	4	5	6	7	8	9	10	**Most mo-tivating**

Question concerning educational value

Do you think the simulator is a suitable training modality in a skills-lab?
N/A

Most un-suited	0	1	2	3	4	5	6	7	8	9	10	**Most suited**

Do you think using this simulator is a good way to prepare for a real-life arthroscopic operation?

Yes*	**No***

*Please specify your answer:

At what stage in the residency curriculum do you think the simulator will be most valuable as a training modality?

Suggestions / Improvements

Please mention at least two points

End of questionnaire. Thank you very much for your cooperation!

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