Original Article

Validation of an Internally Developed Knee Model Designed to Facilitate Instruction in Practice of Arthrocentesis of the Knee

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Objective: To validate an internally developed knee model for training knee arthrocentesis.

Materials and Methods: The present cross-sectional study was conducted at Siriraj Hospital (Bangkok, Thailand) between June 2017 and March 2018. The model was designed to closely simulate the characteristics of the knee so that trainees could learn and practice knee arthrocentesis. The model was validated by seven rheumatologists or orthopedists with long-term experience teaching arthrocentesis, 30 residents, and 155 6-year medical students (MS). The questionnaire response options were 'very poor', 'poor', 'fair', 'good', and 'very good'. The target of evaluation was that 80% of participants would rate the model as good to very good.

Results: All instructors evaluated the model as good to very good for simulated human knee, ability to perform the process as done in a real patient, suitability for practice, safety, convenience, and global quality. More than 80% of MS and residents rated good to very good for simulated human knee, safety, convenience, perceived increase in experience and confidence, and global assessment.

Conclusion: The evaluated knee model was shown to be a valid tool for teaching arthrocentesis. This model should be considered a suitable tool for knee arthrocentesis training and practice.

Keywords: Validation, Knee model, Knee arthrocentesis, Part-task trainer

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Knee pain is a common health problem worldwide with a prevalence of 20% to 50%(1). There are various causes of knee pain with effusion, including infection, crystal-induced arthritis, and degenerative diseases. These conditions can be differentiated and diagnosed by synovial fluid analysis(1). Therefore, the detection of knee effusion and the ability to perform arthrocentesis are essential skills for medical practitioners. As a result, the Medical Council of Thailand has added knee arthrocentesis to the list of procedures that physicians must learn before they can graduate from medical school(2).

Competency in the knee arthrocentesis procedure is best achieved via practice in human patients in real-world clinical practice(3,4); however, learning and practice on patients may not be feasible for all trainees. Moreover, patient safety is a concern in an instructional setting. Alternatively, simulation-based medical education facilitates the acquisition of clinical skills with no risk to patient safety(5). Siriraj Hospital

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is Thailand's largest university-based medical center. Since July 2012, a hands-on, structured knee arthrocentesis workshop using a synthetic knee model had been arranged for and attended by all students in their final year of medical training at Siriraj Hospital. This training program was shown to be successful for improving medical student confidence in performing knee arthrocentesis procedure with sustained knowledge, as evidenced by short-term follow-up assessment(6).

The previous knee model for arthrocentesis training, developed by the authors' center in 2003(7), was not suitable for a large group of trainees. Therefore, commercially available knee models were used instead. However, those commercial models had some inherent weaknesses, including inability of the student to practice detection of fluid accumulation and the development of observable puncture marks on the synthetic skin and synovial sac after 50 punctures. To obtain an affordable knee model, the authors set forth to internally develop a new and improved part-task trainer for teaching and practicing knee arthrocentesis. The aim of the present study was to validate the internally developed knee model designed to teach arthrocentesis.

Materials and Methods

The present cross-sectional validation study was conducted at the Division of Rheumatology, Department of Medicine, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand between June 1, 2017 and March 18, 2018. The protocol for the present study was approved by the Siriraj Institutional Review Board (SIRB) (COA no. Si298/2017), and written informed consents were obtained from all participants. The present study complied with the principles set forth in the 1964 Declaration of Helsinki and all of its subsequent amendments.

Characteristics of the internally developed knee model

The knee model was designed to be a part-task trainer for use in teaching knee arthrocentesis to 6-year medical students. The design objectives included 1) the knee model would provide a simulated anatomic setting so that knee arthrocentesis could be performed in a similar way as it would be performed in a real human patient, 2) the use of self-healing synthetic skin so that no needle marks would be observed on the synthetic skin or synovial sac after at least 50 needle punctures, and 3) the model would be from mid-thigh to mid-lower leg in length, where students would be able to palpate the significant landmarks for arthrocentesis, fluid could be obtained via needle aspiration if the needle was correctly inserted (medial or lateral suprapatellar or parapatellar approach) into the joint cavity, continuous aspiration could be performed during use of the model, and the model would include gross representations of removable bones, muscles, and tendons to the combined satisfaction of one orthopedist (Vanadurongwan B) and one rheumatologist (Chiowchanwisawakit P). The model was be designed and developed by Chongpipatchaipron S, and it was to be evaluated and amended to achieve the design objectives by Vanadurongwan B, Chiowchanwisawakit P, and Chongpipatchaipron S.

Evaluation questionnaire

Two different questionnaires were developed. One questionnaire was used for teachers, and the other for learners of knee arthrocentesis. Both questionnaires were divided into two parts. The first section was a quality assessment, with rating by 5-option Likert scale (very poor, poor, fair, good, very good), and the second section consisted of open-ended elicitations for comments and suggestions from the respondent. The questionnaires were designed and approved by an orthopedic lecturer (Vanadurongwan B) and a rheumatology lecturer (Chiowchanwisawakit P).

The first part of the lecturer's questionnaire evaluated quality specific to 1) adult human size, 2) human-like surface anatomy, 3) human-like skin quality, 4) demonstrating gross muscle around the knee, 5) ability to find the surface landmark for needle insertion and aspiration similar to the process performed in clinical practice, 6) suitability for practicing knee arthrocentesis, 7) convenient for use as a teaching tool, 8) durability, and 9) global quality.

The first part of learner's questionnaire evaluated quality relating to 1) adult human size, 2) realism of surface anatomy, 3) realism of inner anatomical structure, 4) realism of skin tone, 5) convenience, 6) safety for use, 7) perceived increase in experience in performing knee arthrocentesis, 8) perceived increase in confidence in performing knee arthrocentesis, and 9) global assessment.

Participants and validation

There were two processes, formative and summative. The formative evaluation process to improve quality included one senior medical technology lecturer, and two senior rheumatologists

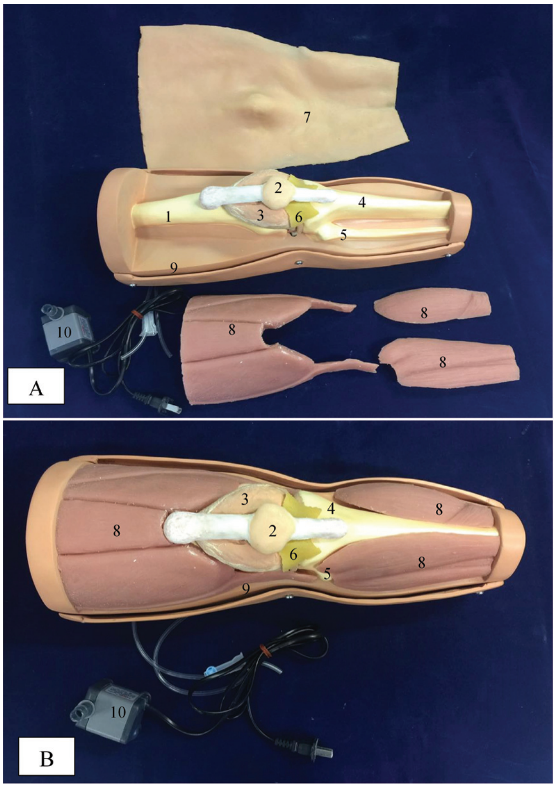

Figure 1. The internally developed knee model disassembled (A), and assembled minus the synthetic skin (B).

1=synthetic femur bone; 2=synthetic patellar bone with quadriceps and patellar tendons; 3=synthetic synovial sac; 4=synthetic tibial bone; 5=synthetic fibular bone; 6=synthetic fat pad; 7=synthetic skin; 8=synthetic muscles, including the quadriceps femoris, tibialis anterior, gastrocnemius, and soleus; 9=groove for affixing the synthetic skin; and 10=water pump

with combined teaching experience of more than 30 years. That group rated the model as good to very good for most items, except for one lecturer who rated human-like skin quality, convenience, and global quality as fair.

Regarding the skin, the synthetic skin used in the present study model was quite soft, but it had a slightly higher resistance than human skin. To assess skin durability, the authors punctured the synthetic skin 100 times at exactly the same point and no change in the skin was observed. As such, a decision was made that there would be no changes to the synthetic skin. However, and in contrast, to reduce resistance during aspiration, the synovial sac was made thinner.

The final model was completed at the end of August 2017. It was a model of the right adult leg. Its dimensions were 15 cm in width × 43 cm in length × 14 cm in height, and it weighed 2.3 kg. It was made of rubber, silicone, and polyester resin. The components of the model included simulated bone (femur, tibia, fibula), a refillable synovial sac with two tubes, a simulated patella with the quadriceps and patellar tendons that could be attached to the femur and tibia, simulated muscle (quadriceps femoris, tibialis anterior, gastrocnemius, and soleus), synthetic skin, and a groove for affixing the synthetic skin to the model (Figure 1). The synovial sac was filled with fluid from a 12×12×12 cm plastic container via a water pump (power 5.5 to 6.5 W, Qmax 400 L/hour, Hmax 0.65 m). The system was designed to keep the synovial sac continuously full during use of the knee model. The model could be used to practice ballottement to assess whether there was any fluid in the joint. All components were separately replaceable if damaged.

Regarding the summative validation, three groups with different levels of experience were invited to anonymously evaluate the model. The evaluation forms were sent in the box. Seven experts in arthrocentesis with at least five years of experience teaching knee arthrocentesis to medical students participated to evaluate the model from the perspective of a teacher. The other participants, included 30 medical residents and 155 6-year medical students, participated to evaluate the model from the perspective of a learner. The target of evaluation for summative validation was that 80% of participants would rate the model as good to very good.

Statistical analysis

The convenience sampling method was used, and the authors envisaged that the study population would include seven experienced lecturers, 30 medical residents, and at least 100 6-year medical students during the 2017 academic year. Imputation was not conducted for missing data. Data were presented as number and percentage.

Results

Seven (100%) lecturers evaluated the model as good to very good for all items. Of the 186 medical students attending the knee arthrocentesis workshop during the study period, 155 (83.3%) participated in the validation study. Fifty-six (36.1%) participants had no experience in knee arthrocentesis before attending the workshop. More than 80% of the medical students rated the characteristics and related perceptions of the knee model as good to very good (Table 1), including the global assessment [93% (95% confidence interval 89 to 97)]. Regarding the 30 medical residents that were enrolled, all of them

Table 1. Assessment of the internally developed knee model by 6-year medical students and medical residents

Items	Quality-rating scale; n (%)							
	Medical students (n=155)				Medical residents (n=30)			
	Poor	Fair	Good	Very good	Poor	Fair	Good	Very good
Characteristics								
Anatomical structure	0 (0)	9 (6)	53 (34)	93 (60)	0 (0)	1 (3)	13 (43)	16 (53)
Size	1 (1)	5 (3)	51 (33)	98 (63)	0 (0)	0 (0)	11 (37)	19 (63)
Color	1 (1)	6 (4)	39 (25)	109 (70)	0 (0)	0 (0)	12 (40)	18 (60)
Convenient	1 (1)	9 (6)	49 (32)	96 (62)	0 (0)	0 (0)	14 (47)	16 (53)
Safety	1 (1)	6 (4)	48 (31)	100 (65)	0 (0)	0 (0)	11 (37)	19 (63)
Related perceptions								
Human-like surface anatomy	1 (1)	17 (11)	64 (41)	73 (47)	0 (0)	3 (10)	15 (50)	12 (40)
Perceived increase in experience	1 (1)	13 (8)	56 (36)	85 (55)	0 (0)	1 (3)	14 (47)	15 (50)
Perceived increase in confidence	1 (1)	13 (8)	54 (35)	87 (56)	0 (0)	2 (7)	12 (40)	16 (53)
Global assessment	0 (0)	11 (7)	55 (36)	89 (57)	0 (0)	0 (0)	13 (43)	17 (57)

had experience in performing knee arthrocentesis. More than 90% of the residents evaluated the model as good or very good for all items, including the global assessment (100%). The following comments were received from study participants: 'Insufficient differentiation between the medial and lateral aspects of the knee' (six lecturers), well-defined landmark for needle aspiration' (six lecturers), 'too easy to find the landmark' (two medical students), 'suitable for finding the landmark' (two medical students), 'good understanding of the structure of the knee and the landmarks for arthrocentesis' (one medical student), 'the synthetic skin is more resistant than human skin' (nine medical students and two residents), 'good quality synthetic skin' (nine medical students and five residents), perceived good sense of aspiration' (one medical student and one resident), and, 'the synovial sac is too resistant to puncture' (one medical student and one resident). One medical student suggested that it would be great to know the needle position when inserting it.

Discussion

The results of the present study revealed the authors' internally developed knee model to be a valid tool for teaching knee arthrocentesis, and it was validated by a wide range of experience in arthrocentesis from beginners to experts, and in both learners and teachers as a knee model developed by the authors' center in 2003[7]. In previous arthrocentesis workshops, the authors observed a few novices needed to review and see the anatomy around the knee to better understand how to identify the landmark for needle puncture and to determine the direction of the needle as was described in Waikakul et al's report[7]. In response, the authors included the gross anatomy above the knee, at the knee, and below the knee in the new internally developed knee model. There was a wide range of comments among evaluators. This difference between teachers and learners is likely due to the fact that the designers and the lecturer evaluators all know the essential components of the knee arthrocentesis procedure, so there was much less dissimilarity among their observations and comments.

Practicing with this model was suitable for medical students because they could perform knee arthrocentesis in a similar way as to how to perform in real human patients. There are different approach portals for knee arthrocentesis (medial or lateral suprapatellar, parapatellar, or infrapatellar approaches), however, no approach is 100% accurate[8]. The previous model allowed aspiration of fluid only via the suprapatellar approaches[7]. In contrast, the present part-task trainer allows aspiration of fluid via the medial or lateral suprapatellar and parapatellar approaches because they are common approaches with a high success rate. These techniques are performed with the knee in extension. Moreover, the fact that no puncture mark was visible after the needle was withdrawal ensured that the next student would have to use the appropriate landmarks to identify the puncture site. This represents an improvement over the previous model[7]. The knee model evaluated in the present study was also suitable for use in a large volume and continuous workshop setting, which is in contrast to the limitations observed in the previously used knee model at the authors' center[7]. With some modifications, the internally designed and developed knee model may also have benefit for teaching and practicing knee injection, because injection and aspiration are very similar procedures. In addition, it has a durable synthetic skin and each component could be repaired or replaced separately. Furthermore, It is affordable. The prototype costed 760 USD. The production units were even less expensive.

Limitation

Some weaknesses of the authors' knee model were identified. First, the synthetic skin and synovial sac were both found to be more resistant to needle puncture than human tissue. However, it was still accepted by most raters. Although, the authors have planned to improve both the synthetic skin and the synovial sac in the future, the realism of the materials used was secondary to the authors' main focus. Second, the medial and lateral aspects of the knee were not well-differentiated even though significant landmarks for determining the point of needle penetration were sufficiently palpable. However, this observed design deficiency did not inhibit the arthrocentesis process. All of these observed shortcomings can be corrected or improved in the future version knee model.

Conclusion

The present internally developed knee model was shown to be a valid tool for teaching and practicing arthrocentesis. In its current form, this model should be considered a suitable tool for knee arthrocentesis training and practicing. However, additional enhancements, such as modification of the synovial sac, will further enhance the similarity between the authors' internally developed knee model and the human knee.

What is already known on this topic?

A structured knee arthrocentesis workshop using a synthetic knee model was shown to be successful for improving medical student confidence in performing the knee arthrocentesis procedure with evidence of sustained knowledge.

What this study adds?

An internally developed knee model could be a suitable tool for teaching and practicing knee arthrocentesis.

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Conflicts of interest

All authors declare no personal or professional conflicts of interest relating to any aspect of the present study.

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