

## INJECTION OF PROXIMAL INTERPHALANGEAL JOINT BY HAPTIC SUPPORTED VIRTUAL REALITY ENVIRONMENTS

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### ABSTRACT

*In Medicine, Joint injections are the leading procedures of frequent usage. Effects of Haptic supported virtual reality environments on joint injections which give serious pain to patient, if haven't been done absolutely right, was aimed to analyze in this research. These environments allow the user to try the developed application for infinite time. In this paper, a haptic supported virtual reality environment was designed for the physicians. An algorithm was developed for this environment, and coded with C++ based Quick-Haptics programming language. A 3D hand model which is created from computed tomography images and a 3D syringe were used in the developed application. The developed virtual reality application was used with Geomagic™ haptic device and head mounted Display by randomly selected medical students who answered a questionnaire consisting 27 questions after the trial of the application. Questionnaire result was analyzed with machine learning by using J48 algorithm in WEKA software. Analyses showed that Haptic supported virtual reality environments give more motivation and influences students with the opportunity of human computer interaction.*

**Keywords:** Haptic Devices; OpenHaptics; Virtual Reality Environments; Injection; Software Development; Human Computer Interaction

### INTRODUCTION

Haptic perception means to touch (Salisbury J. , 1999). In this paper, the usage of the word “haptic” can be defined as; interaction of a person with a virtual object by way of touch (Avila, 1996). Haptic devices which contain virtual objects have been studied for many years. The first usage of haptic devices was tele remotes which were used to carry hazardous chemical and nuclear stuffs in 1940s. Due to the progress of Phantom™ haptic device in early 1990s, haptic interaction usage for information technologies grew significantly (Salisbury & Srinivasan, 1997) .

Haptic devices return some types of feedbacks. These feedbacks are categorized as Force and Tactile. Force Feedback reproduces weight, motion interdiction of objects, while Tactile Feedback enables users to feel the roughness, edges and warmth of the objects (Burdea, 2000). Tactile Feedback sensory was used for the approaches of haptic object recognition and localization (Aggarwal & Kirchner, 2014). There are more examples of feedback studies like positioning joy-sticks (Rubio-Sierra & Stark, 2003), sensation of tactile soft matters (Heller, 2002), surgical training platforms ( Zhang, et al., 2012), medical inspection in haptic supported virtual reality environment(HSVRE) ( Li, et al., 2015), and multimodal neuro-surgery applications ( Kuroda, Kamada, Hayashi, Imura, & Oshiro, 2011).

The usage of HSVRE, are widely growing in our everyday lives with respect to the synchronous expansions in software and hardware of computer sciences. There is a remarkable acceleration in process of entertainment and education in HSVRE, due to developing 3-D images and animations, head mounted displays (HMD) and haptic devices for human-computer interaction ( KAYABAŞI, 2005).

Ordinary class implementations that are taught all around the Globe is linked on learning with optic senses, such as course-books, written formulas and graphics (Jones, et al., 2014). HSVRE systems play a more fertile part on (Civelek, 2015) abstract notions than ordinary education manners (Bozkurt, 2008).

Haptic device usage in several education systems is rapidly increasing. The importance of HSVRE is the chance of repetitive trial that is given to the user (Civelek, Ucar, & Gokcol, 2014). HSVRE usage for medical, nursing and dental students' practices occupies an important place. A Previous research shows that with additional haptic education, nursing students learned quicker than the individuals that were just educated with practical exercises for venipuncture injection (Jung, et al., 2012). There are also studies on haptic supported injection implementations, such as polymethylmethacrylate (PMMA) injection into cancellous bone (Lian, Chui, & Teoh, 2008), Micro-robotic cell injection (Ghanbari, Horan, Nahavandi, Chen, & Wang, 2014), epidural injection simulator (Dang, Annaswamy, & Srinivasan, 2001), Biological-Cell Injection (Ammi & Ferreira, 2005), intravenous injection simulator (Tsai, Fung, Tsai, Jeng, & Doong, 2008).

Joint injection is a drug application which is applied to joint space or periarticular tissue. The aims of application are treatment and relieve symptoms of directly joint or joint components (Dinçer, 2013). In medicine, Syringe is used to inject anti-inflammatory medicines or to extract synovial fluid to aid diagnosis for proximal interphalangeal joint diseases, such as, trigger fingers, rheumatoid arthritis, osteoarthritis and systemic lupus erythematosus (Shinomiya, et al., 2015). In this paper, an education method of haptic supported virtual injection system was aimed to develop.

### **Implementation of HSVRE & Haptic Device Fields**

In near future, virtual reality for 3-D visualization and haptic supported machines will fill a wide space in human life. HSVRE study is a promising area. The best point of HSVRE technology is its adaptable features to every field like geography, entertainment, science, medicine, learning systems, architecture, and engineering.

First of all, haptic technologies are used in medical students' education applications, such as surgical operations, neuro-surgery (Lemore, Banerjee, Luciano, Neckrysh, & Charbel, 2007), co-worked surgeoncies' (Qin, Choi, Poon, & Heng, 2009), force-feedback imaging of cardiac surgery virtual platforms (Nakao, et al., 2002), risky cardiovascular involvements (Mayer, et al., 2007) tactile platforms of vertebral insertion (Luciano, et al., 2013). HSVRE technologies are also used for technical improvement of the haptic devices (Çavuşoğlu, Feygin, & Tendick, 2002) and machine-based experiments of physics, mathematics and the other parts of scientific studies (Yan, Hou, Zhang, Kang, & Zheng, 2009). Also some social aimed needs could be area of these kinds of investigations (Kaklanis, Votis, & Tzouvaras, 2013).

## **RESEARCH METHODOLOGY**

Effects of HSVRE usage on education of joint injection was aimed to observe. During this research a 3D hand model was created in 3Dslicer™ application which provides users to change computed tomography (CT) images to 3D objects. This hand model was set in a virtual reality environment and a haptic supported simulation was designed. 35 randomly selected medical students were chosen to apply the designed simulation. Moreover, these students were asked to answer a questionnaire consists of 27 questions with the answers of 'Low', 'Medium', 'Good' and 'Very good' except the 27<sup>th</sup> question which had two answers as 'Yes' or 'No'.

WEKA is a widely known, open source machine learning software. Graphical and visual opportunities make WEKA a favorable option for machine learning. It's necessary to have opinions about results of researches. There are some methods for that aim. Accuracy rate, precision, recall and F-measure are one of them (Aydogan, Gencer, & Akbulut, 2008).

Precision and recall are not enough to get exact results. *F-measure*, which is harmonic average of precision (P) and recall (R), is defined to solve this problem (Han & Kamber, 2006). F-measure value has better learnt the relationship between algorithm classes that are close to 1. F-measure is calculated as follows:

$$\text{F-measure } (F) = \frac{2 * P * R}{(P + R)}$$

*Kappa value* (K) describes the reliability of comparison between observers ( (Cohen, 1960), (Fleiss, 1971) ). The purposeful interval of Kappa-value is between -1 and 1. K is 1 when there is an exact concurrence comparison between observers. Negative values of kappa (K<0) are meaningless in terms of reliability. The range of 0.41 and 1.0 is acceptable value for K (Landis & Koch , 1977). If P<sub>o</sub> is acceptable rate and P<sub>c</sub> is the expected rate, K is calculated as follows:

$$\text{Kappa value } (K) = \frac{(P_o - P_c)}{(1 - P_c)}$$

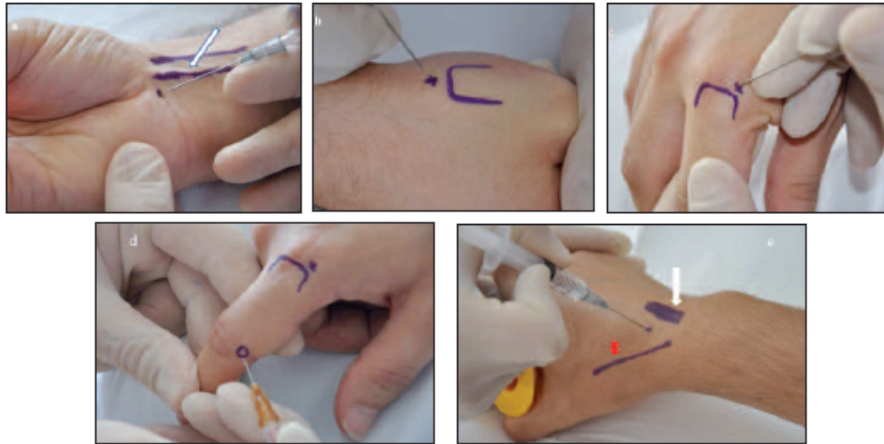
### Procedure

Common indications for joint injections include insertion of therapeutic agents like steroids, lidocaine, and hyaluronic acid to relieve inflammation, pain and to increase function of joint (Sallis). Indications of joint injections are inflammatory conditions such as rheumatoid arthritis and osteoarthritis. Please refer table1 to see common indications for joint injections (Dinçer, 2013).

**Table 1.** Common Indication for Joint Injections

Inflammatory Arthritis
Rheumatoid Arthritis And Juvenil Rheumatoid Arthritis
Crystal İnduced Arthropaties ( Gout, Pseudogout)
Noninflammatory Arthritis
Osteoarthritis ( Knee, Hip, Shoulder, Hand Joints)
Periarticular Soft Tissue İnjektions
Bursitis
Entrapment Neuropathies (Especially Carpal Tunnel Syndrome)
Epicondylitis
Tenosynovitis

This procedure can be applied to knee, hip, shoulder or hand joints. In this research, Proximal Interphalangeal (PIF) joint injections are focused on. In PIF injection finger should be in semiflexion position so joint space could widen, progress should be on perpendicular axis from medial or lateral of extensor tendon on dorsal face of hand. To progress the joint may be painful and hard to apply. 1.5 cm injector and 0.25-0.5 cc corticosteroid can be used in injection procedure (Dinçer, 2013). (Figure1)



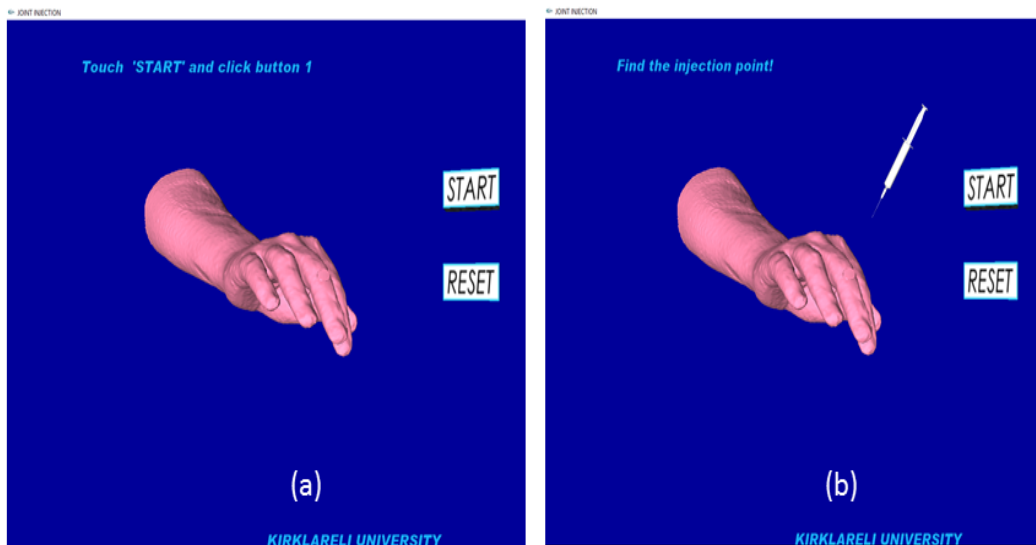
**Figure 1.** Hand joints injections: (a) Carpal Tunnel Syndrome (b) 1. Metacarpophalangeal joint (c) Metacarpophalangeal joint (d) proximal interphalangeal joint (e) Radiocarpal Joint

### 3D Modeling

A 3D hand model was designed in an appropriate file format for the software development environment before the coding process of injection application. The model was aimed to design as in real world. Therefore, CT images were inserted in 3DSlicer™ environment and almost the same hand model created with the format of STL which is suitable for the coding language. Afterwards, for the adjustment and localization of this created hand model, Rhino™ environment was used.

### Software Development

One of the significant steps for HSVRE is application coding. An improvement on education of injection usage of medicine students is aimed with the developed application. Knowledge of absolute injection point is crucially important. There are rules that must be followed before and during the injection (Sallis). HSVRE application that provide education must be developed proper to these rules. An algorithm was developed to explore a solution for the problem of critical proximal interphalangeal joint injection. (Figure2)



**Figure 2.** Starting View of Application

HSVRE of joint injection was coded on visual studio environment with C++ and Quick-Haptics. Algorithms of buttoncallback, touchcallback, force and tactile feedbacks were coded. In this application, a syringe attached to haptic device. While the user is trying to insert to not the desired injection point, a force applied to device and user cannot insert inside the model. On the other hand, when the user finds the injection point, application warns him/her and if the injection is being done with the aimed angle, algorithm lets the user for the injection and syringe inserts through the model. (Figure 2) System gives success message and haptic device doesn't put on resistance during injection to this point. Arm does its process easily.

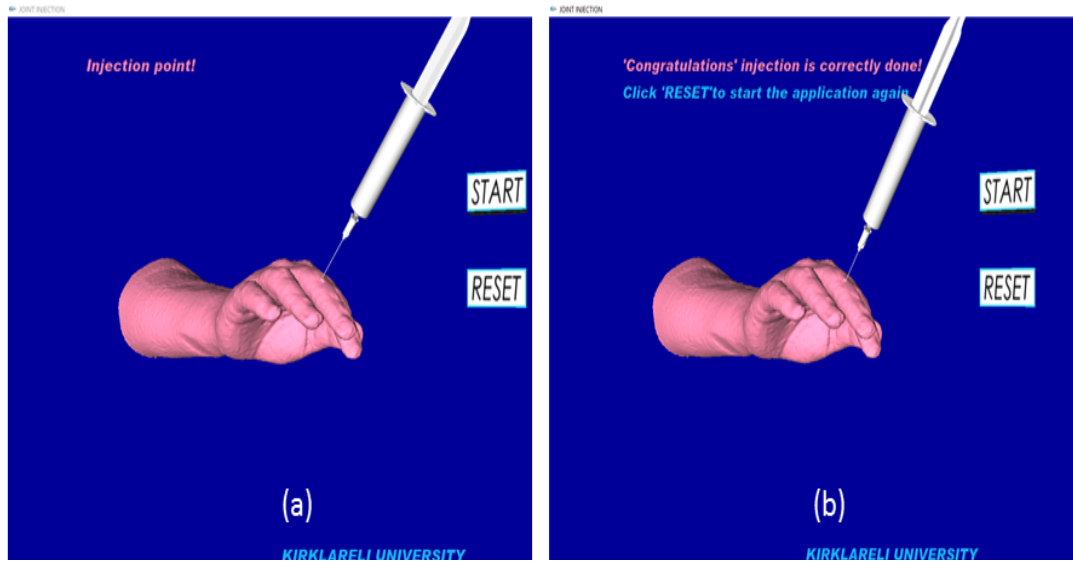


Figure 3. (a) During the Injection (b) Success Message

In order to continue the application, reset button can be used for new trials. Repetitive trials of haptic education are thought to make the learning of the joint injection more obvious. (Figure 3)

### Algorithm of the Application

A cursor is created and attached with haptic device after the creation of display window. Objects are added to the environment. Coordinates and features of the objects are defined for the workspace. During the simulation position of cursor and object are always compared. After the interaction of object and cursor, functions work as a loop to give returns to the user. (Figure 4)

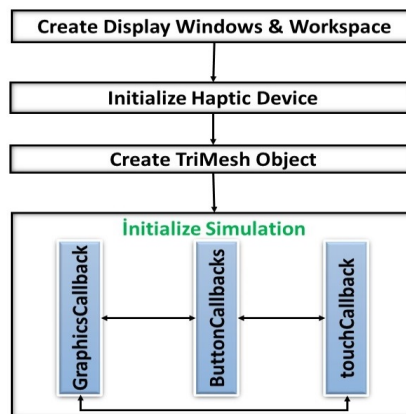
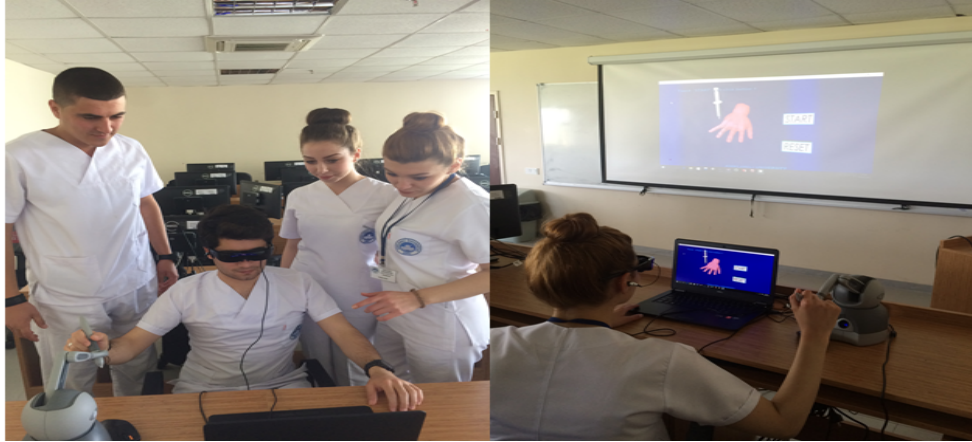


Figure 4. Algorithm of the Developed Software

**Implementation of Learning Environment**

Application, 3-D display units, haptic device and computer interaction and HSVRE was developed. For visualization of virtual reality environment head mounted display and Geomagic™ were used.



**Figure 5.** Medical Students Trying the Application

Head mounted display (HMD) which gives 3-D visualization was mounted to the participants' head and developed application activated during process (refer to Figure 3). Haptic device's touch arm is used by hand to control syringe on the screen. Inserting of Syringe isn't allowed to any part of hand, except the desired and marked joint region. Haptic arm put up resistance and doesn't insert in other parts of the hand. Therefore, user was stimulated by a given force feedback. A difficulty occurs on arms motion, during syringe's rub to other parts of the hand.

35 students from faculty of health in Kırklareli University tried the simulation and were asked to answer a questionnaire with 27 questions about haptic devices, HSVRE's, realization of the simulation. According to the questionnaire some analyses were done to observe the efficiency of the application and haptic devices in medical education.(Figure 5)

**RESULTS**

For every question, true classification scores of J48 are better than scores of primitive algorithm ZeroR. This shows that J48 achieve successful learning algorithm. Kappa's statistic value shows that J48 algorithm accomplishes acceptable and successful learning between 0.41 to 0.60 and 0.61 to 1.00.

**Table 2.** ZeroR Algorithm

Question	Kappa Statistic	Correctly Classified Instances	TP Rate	FP Rate	Precision	Recall	F-Measure	ROC Area
14	0	48.57 (17)	0.49	0.49	0.24	0.49	0.32	0.35
15	0	57.14 (20)	0.57	0.57	0.33	0.57	0.42	0.40
17	0	45.71 (16)	0.46	0.46	0.21	0.46	0.29	0.34
18	0	48.57 (17)	0.49	0.49	0.24	0.49	0.32	0.36
21	-0.08	37.14 (13)	0.37	0.46	0.26	0.37	0.28	0.34
22	0	45.71 (16)	0.46	0.46	0.21	0.46	0.29	0.33
24	0	40.00 (14)	0.40	0.40	0.16	0.40	0.23	0.37
25	0	42.85 (15)	0.43	0.43	0.18	0.43	0.26	0.34

In WEKA, for the questions of 14, 15, 17, 18, 21, 22, 24, 25 separated classifications were made with ZeroR primitive algorithm, and 35 samples were classified respectively as 17 ones 48.57%, 20 ones 57.14% , 16 ones 45.71%, 17 ones 48.57%, 13 ones 37.14%, 16 ones 45.71%, 14 ones 40.00%, 15 ones 42.85% of them accurately as seen in Table 1.

**Table 3. J48 Algorithm**

Question	Kappa Statistic	Correctly Classified Instances	TP Rate	FP Rate	Precision	Recall	F-Measure	ROC Area
14	0.67	80.00 (28)	0.80	0.12	0.78	0.80	0.80	0.79
15	0.59	77.14 (27)	0.77	0.13	0.75	0.77	0.76	0.88
17	0.52	71.42 (25)	0.71	0.15	0.73	0.71	0.72	0.86
18	0.63	77.14 (27)	0.77	0.14	0.75	0.77	0.76	0.81
21	0.68	80.00 (28)	0.80	0.10	0.80	0.80	0.79	0.85
22	0.54	71.43 (25)	0.71	0.14	0.67	0.71	0.68	0.71
24	0.56	71.43 (25)	0.71	0.13	0.70	0.71	0.70	0.81
25	0.57	71.43 (25)	0.71	0.12	0.72	0.71	0.72	0.81

In WEKA, for the questions of 14, 15, 17, 18, 21, 22, 24, 25 separated classifications were made with J48 algorithm, and 35 samples were classified respectively as 28 ones 80.00%, 27 ones 77.14% , 25 ones 71.42%, 27 ones 77.14%, 28 ones 80.00%, 25 ones 71.43%, 25 ones 71.43%, 25 ones 71.43% of them accurately as seen in Table 1.

When two tables are compared, it's obvious that F-measures of J48 algorithm are greater than the ones of ZeroR. F-Measure value of J48 algorithm is closer to 1. These results of WEKA analyze shows that j48 accomplished a better machine learning.

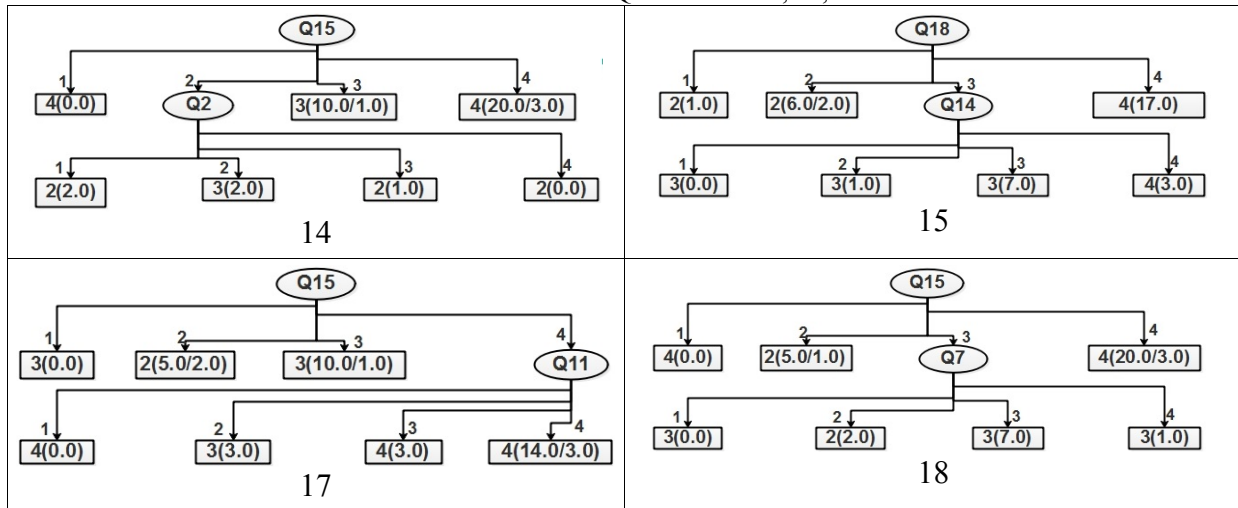
Learning was accomplished in the following questions with j48 algorithm;

- Q2. Does HSVRE motivate you?
- Q7. Do you think using HSVRE with haptic devices in lecturing provides you more efficient learning?
- Q11. Does HSVRE courage you to make researches?
- Q14. Does using HSVRE for applications make easy integration with lessons for students?
- Q15. Can HSVRE make lessons more attractive?
- Q17. Does HSVRE help you to connect the new information with your old knowledge?
- Q18. Does HSVRE give opportunity to see materials which cannot be taken into classrooms?
- Q21. Do designed VR environments provide you to objectify subjects?
- Q22. Do you think working with haptic devices in VR environments can increase your success in medical education?
- Q24. Does HSVRE provide suitable settings for injection applications?
- Q25. Does the designed environment provide you to understand concepts like joint injection?
- Q26. Can HSVRE be used for the preparation of injections?
- Q27. Does the Medical Education supported with HSVRE present a better opportunity than the traditional medical education?

J48 algorithm classified the data set. It divided data by choosing the best root value. Decision tree structure was built for the each correctly learnt question from top to bottom.

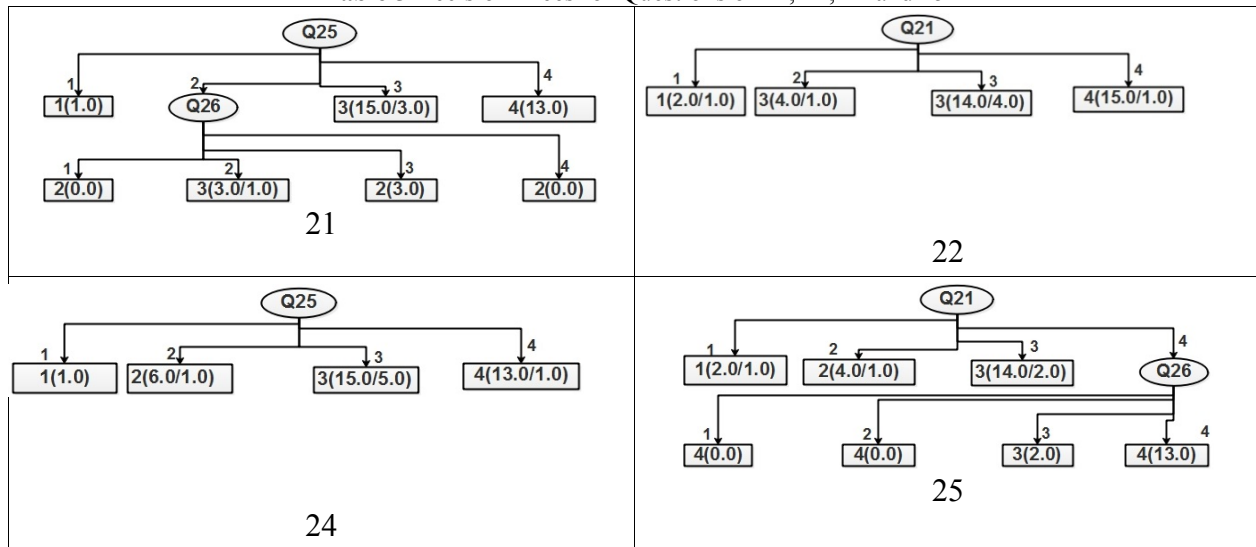
Best root values placed to the top of the tree. Other root values placed through down according to the gain condition. Therefore, graphical representation of the decision trees created with high accuracy as seen in the figures below. Decision tree structure was built by choosing the best root value. Placement of roots according to the sorting of questions that succeed acceptable learning are given in the following figures as decision tree structures.

**Table 4.** Decision Trees for Questions of 14, 15, 17 and 18



When the 14<sup>th</sup>, 15<sup>th</sup>, 17<sup>th</sup> and 18<sup>th</sup> questions are separately based on, respectively best root values are 15<sup>th</sup>, 18<sup>th</sup>, 15<sup>th</sup> and 15<sup>th</sup> questions for the accomplished learning with J48 algorithm. It has been learnt by the j48 algorithm that 26 student for 14<sup>th</sup> question, 27 student for 15<sup>th</sup> question, 23 student for 17<sup>th</sup> question and 25 student for 18<sup>th</sup> question answered “good” or “very good” from the students who answered the questions which are best root values (15, 18, 15, 15) as “good” and “very good”.

**Table 5** Decision Trees for Questions of 21, 22, 24 and 25



When the 21<sup>st</sup>, 22<sup>nd</sup>, 24<sup>th</sup> and 25<sup>th</sup> questions are separately based on, respectively best root values are 25<sup>th</sup>, 21<sup>st</sup>, 25<sup>th</sup> and 21<sup>st</sup> questions for the accomplished learning with J48 algorithm. It has been learnt by the j48 algorithm that 25 student for 21<sup>st</sup> question, 24 student for 22<sup>nd</sup> question, 22 student for 24<sup>th</sup> question and 27 student for 25<sup>th</sup> question answered “good” or “very good” from the students who answered the questions which are best root values (25,21,25,21) as “good” and “very good”.

All students who joined to research and answered the questionnaire answered the 27<sup>th</sup> question as ‘Yes’.



### SUMMARY

Proximal interphalangeal joint injection is a sensitive method which gives a considerable pain to patient, if it isn't done with the proper rules. In this paper, an educational HSVRE algorithm was designed for Medicine students' usage of virtual injection that gives force feedback. If the injection is applied to the desired point by obeying the rules, system allows inserting to the point and success message is given. On the other hand, if the user doesn't obey the rules, system gives force feedback and injection cannot be completed. Haptic supported joint injection provides a very effective chance for medical education due to its repetitive trial advantage.

From the results of machine learning provided by J48 algorithm of WEKA, Medical students who think HSVRE;

1. makes the course more interesting also thinks;
  - it effects the integration to lesson (%74.29), connects the new information with old knowledge (%65.71) gives opportunity to see materials which cannot be taken into classrooms (71.43),
2. gives opportunity to see materials which cannot be taken into classrooms also thinks it makes the course more interesting (%77.14),
3. provides individual to understand concepts of joint injection better also thinks;
  - It provides user to objectify subjects in his/her mind(%71.48) and suitable settings for injection applications (%62.86),
4. provides user to objectify subjects also think;
  - It can increase their success in medical education (68.57and provides individual to understand concepts of joint injection better ( %77.14)

This research shows that HSVRE make easy integration with lessons for students, connects the new information with old knowledge, makes the course more interesting and enlarges the number of materials used in the course. Results also show, it helps students to understand concepts of joint injection better, objectifies subjects in their mind, provides suitable settings for injection applications and can increase their success in medical education. Furthermore, all the students who attended to questionnaire think that education with HSVRE presents a better opportunity than the traditional medical education.

Results of this paper match up with the previous studies ( (Jung, et al., 2012), ( Ghanbari, Horan, Nahavandi, Chen, & Wang, 2014), (Lian, Chui, & Teoh, 2008), (Dang, Annaswamy, & Srinivasan, 2001)) of HSVRE injection. In the future works, injection of other joints of human body and new HSVRE educational applications are recommended to investigate.

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