# Summary of this thesis

Chapter 1 provides the introduction for this study. The frequency of infertility treatment is increasing, but the success rate of such treatment is not increasing. A treatment method called assisted reproductive technology (ART) has a higher success rate than conventional fertility treatment. However, the success rate remains low. This study analyzed uterine features of patients with infertility, and developed a medical diagnosis support system for female infertility, to improve the success rate of treatment.

Chapter 2 describes the analysis of uterine movements in infertile patients by Cine MRI images. The uterus has movements called uterine peristalsis that assist in the transport of sperm. The direction and frequency of uterine peristalsis change during the phase of each menstrual cycle. The upward movement (corpus to fundus) occurs in the ovulation phase, and downward movement (fundus to corpus) occurs in the menstrual phase, whereas there are no movements in the luteal phase. However, random and mixed movements occur in all phases of the cycle in infertile patients. These peculiar characteristics of infertile patients were observed because of advances in MRI technology in recent years. To date, uterine movements in patients with infertility have not been investigated in detail. Therefore, it is not known which movement has negative effects on obtaining pregnancy. To clarify the characteristic uterine movements in patients with infertility, it was necessary to develop a new evaluation technique. This research found six fundamental uterine movements, of which two movements affected infertility. The six movements were found by using visual simulation based on the three-dimensional finite difference time domain (FDTD) method with a wave equation. Four physicians compared the Cine MRI and simulated images by direct observation, and found that the simulated images successfully mimicked all Cine MRI images. This analysis demonstrated that the six movement patterns were effective at assessing the unique characteristics of infertile patients. The two movements with effect for infertility were found chi-square test. The direction of uterine motion in MRI images was compared with the ideal direction of uterine motion. It was concluded that the two movements were wrong motions by investigating the un-ideal movements. Furthermore, a simulation in this study found that uterine peristalsis had a constant propagation velocity of 0.68 mm/sec. Using this simulation velocity feature, a prediction system for uterine movement types was developed by Cine MRI images. This system was composed of a convolutional neural network (CNN). An evaluation experiment showed that the system had a 71% prediction accuracy for sagittal plane images. A system without velocity information had a 64% prediction accuracy for sagittal plane images. These results demonstrated that velocity information was important for uterine movement analysis.

Chapter 3 describes the development of a diagnostic support system that

predicts pregnancy outcomes by the analysis of uterine movements detected using ultrasonic images. In infertility treatment, it is typical to evaluate the endometrial shape. Before ovulation, the endometrium has a leaf-like pattern. After ovulation, the endometrium has a uniform shape, known as the homogenous pattern. Physicians evaluate the optimal phase for pregnancy outcome based on endometrial shapes. Based on the relationship between endometrial shapes and phases of the menstrual cycle, it is generally considered that a leaf pattern represents the optimal time for achieving pregnancy, and the homogenous pattern represents the time of a low pregnancy rate. Endometrial shapes in ultrasonic images are evaluated by direct observation. However, it is difficult to correctly evaluate endometrial shapes from ultrasonic images. The fertility treatment may fail even if the physician identifies a leaf pattern, and treatment may succeed even if the physician identifies a homogenous pattern. The CNN system developed in the current study predicted pregnancy outcome by velocity information. Experiments compared the velocity-based and shape-based systems. The shape-based systems predict the optimal uterine features for pregnancy success based on endometrial shape. In this study, two shape-based systems were developed. One used a local binary pattern (LBP), and the other used a CNN. The current findings revealed that the velocity-based system provided similar accuracy to the shape-based systems. However, the output of the velocity-based system, the area under curve (AUC) for the receiver operating characteristic (ROC) curve, provided a higher value than the shape-based systems. The AUC values of the LBP shape-based, CNN shape-based, and velocity-based systems were 0.62, 0.65, and 0.72, respectively. These results showed that the analysis of the velocity of uterine movements was effective for pregnancy outcome prediction. Previous clinical evaluation did not target the uterine movement but only the endometrial shape. Therefore, this study has revealed a new treatment approach for infertility.

Chapter 4 presents the scientific significance and potential contribution of the novel research in this thesis. This study revealed that all uterine peristalsis displayed at a constant propagation velocity. This novel velocity feature was applied to pregnancy outcome prediction from uterine analysis. In clinical image analysis for infertility, it is very important to analyze uterine movement because uterine movement and infertility are closely related. To date, it has been difficult to analyze uterine movement by image analysis. The large variation in endometrial shape and size between individuals, presented a challenge to generating a generalized prediction model. The new velocity feature overcomes these problems and is expected to contribute to the growth of related studies.