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Development of a Real-time Autonomous Ultrafiltration Control Agent Using Deep Reinforcement Learning

Min Woo Kang
Department of Internal Medicine-Nephrology, Seoul National University Hospital, Korea, Republic of

Objectives : The global prevalence of end-stage kidney disease (ESKD) patients is increasing, emphasizing a growing need for home dialysis. However, since home hemodialysis lacks the close monitoring by healthcare professionals as in clinical settings, the development of artificial intelligence capable of autonomously adjusting dialysis in real-time is essential.
Methods : We utilized data from hemodialysis patients at MacKay Memorial Hospital in Taiwan, an open data source from Scientific Data. The aim of this study is to develop reinforcement learning (RL) agent capable of autonomously adjusting ultrafiltration in real-time during dialysis. Deep learning model predicting blood pressure during dialysis was developed. Using this model, a virtual dialysis simulator was created to establish a Markov Decision Process environment. We utilized the Fully Parameterized Quantile Function (FQF) for online RL and Conservative Q-Learning (CQL) for offline RL. The CQL model was created by adding CQL loss to IQN (Implicit Quantile Networks). Both models were evaluated using 4,480 virtual patients through the simulator.
Results : Data from a total of 1,072 patients and 27,508 dialysis sessions were used in this study. The simulator's blood pressure prediction abilities showed Mean Absolute Errors (MAE) of 5.12 and 2.87 mmHg for SBP and DBP, respectively, on the train data, while on the test data, the MAE was 6.02 and 3.29 mmHg, respectively. The online RL model successfully achieved an average weight reduction with mean error of 0.26 kg compared to the target, and 896 cases of hypotension occurred. The offline RL model achieved weight reduction with mean error of 0.04 kg compared to the target, and 909 cases of hypotension occurred.
Conclusions : Using an open data source, we developed RL agent capable of autonomously adjusting ultrafiltration during dialysis through reinforcement learning. It appears that with refined data in the future, the development of a self-regulating dialysis machine is plausible.

Table.jpg

Table 1. Performance of simulator for predicting blood pressure

Metric	SBP in train data	DBP in train data	SBP in test data	DBP in test data
MSE	75.3740	26.0134	103.1172	32.8790
RMSE	8.6818	5.1003	10.1547	5.7340
MAE	5.1177	2.8714	6.0248	3.2894
R^2	0.8943	0.8847	0.8440	0.7893

SBP, systolic blood pressure; DBP, diastolic blood pressure; MSE, mean squared error; RMSE, root mean squared error; MAE, mean absolute error

Table 2. Performance of online and offline reinforcement learning models

	Total	Weight gain ≤ 2kg	Weight gain > 2kg	SBP ≤ 120 mmHg	SBP > 120 mmHg	Age ≤ 50 years	Age > 50 years
Online RL							
RMSE[a]	0.5120	0.0722	0.6584	0.5854	0.4262	0.5108	0.5133
MAE[b]	0.2621	0.0052	0.4335	0.3427	0.1817	0.2609	0.2634
R^2[c]	0.9260	0.9999	0.8125	0.8820	0.9621	0.9262	0.9257
Hypotension count	896 (0.20)	0 (0.00)	896 (0.33)	0 (0.00)	896 (0.40)	448 (0.20)	448 (0.20)
Offline RL							
RMSE[a]	0.2098	0.2060	0.2123	0.1661	0.2459	0.2519	0.1568
MAE[b]	0.0440	0.0424	0.0451	0.0276	0.0605	0.0635	0.0246
R^2[c]	0.9886	0.8446	0.9847	0.9954	0.9819	0.9806	0.9966
Hypotension count	909 (0.20)	6 (<0.01)	903 (0.34)	0 (0.00)	909 (0.41)	459 (0.20)	450 (0.20)

MSE, mean squared error; RMSE, root mean squared error; MAE, mean absolute error

[a]RMSE for weight gain and weight reduction by reinforcement learning model

[b]MAE for weight gain and weight reduction by reinforcement learning model

[c]R^2 for weight gain and weight reduction by reinforcement learning model

Table.jpg

Figure 1. Scatter plot of total ultrafiltration and weight reduction

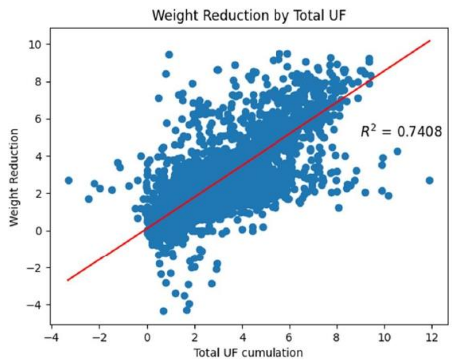

Figure 2. Network of blood pressure predictor of simulator

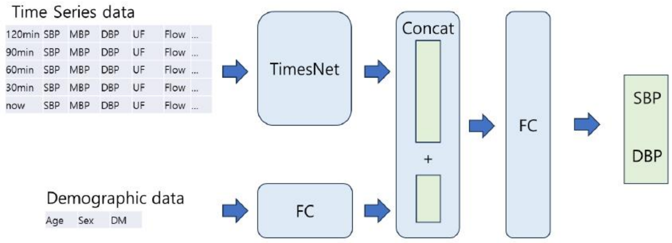

Figure 3. Network of Q function of reinforcement learning