J. Cell Commun. Signal.
DOI 10.1007/s12079-015-0293-7

RESEARCH ARTICLE

WT1 expression is increased in primary fibroblasts derived from Dupuytren's disease tissues

Justin Crawford[1,2] · **Christina Raykha**[1,2] · **Daevina Charles**[5] · **Bing Siang Gan**[1,2,3,4] · **David B. O'Gorman**[1,2,3,5]

Received: 12 March 2015 / Accepted: 16 April 2015

Abstract Dupuytren's disease (DD) is a fibroproliferative and contractile fibrosis of the palmar fascia that, like all other heritable fibroses, is currently incurable. While DD is invariably benign, it exhibits some molecular similarities to malignant tumours, including increased levels of ß-catenin, oncofetal fibronectin, periostin and insulin-like growth factor (IGF)-II. To gain additional insights into the pathogenesis of DD, we have assessed the expression of *WT1*, encoding Wilm's tumour 1, an established tumour biomarker that is syntenic with *IGF2*, the gene encoding IGF-II in humans. We found that *WT1* expression is robustly and consistently up regulated in primary fibroblasts derived from the fibrotic palmar fascia of patients with DD (DD cells), whereas syngeneic fibroblasts derived from the macroscopically unaffected palmar fascia in these patients and allogeneic fibroblasts derived from normal palmar fascia exhibited very low or undetectable *WT1* transcript levels. WT1 immunoreactivity was evident in a subset of cells in the fibrotic palmar fascia of patients with DD, but not in macroscopically unaffected palmar fascia. These findings identify *WT1* expression as a novel biomarker of fibrotic palmar fascia and are consistent with the hypothesis that the pathogeneses of DD and malignant tumours have molecular similarities.

Keywords Dupuytren's disease · Fibrosis · Wilm's tumor 1 · Biomarker

Justin Crawford and Christina Raykha contributed equally to this work.

✉ David B. O'Gorman
dogorman@uwo.ca

Justin Crawford
jcrawfo9@uwo.ca

Christina Raykha
craykha@hotmail.com

Daevina Charles
dcharle4@uwo.ca

Bing Siang Gan
bsgan@rogers.com

[1] Cell & Molecular Biology Laboratory, Roth|McFarlane Hand & Upper Limb Centre, London, ON, Canada

[2] Lawson Health Research Institute, 268 Grosvenor Street, Room E2-137, London, ON, Canada N6A 4V2

[3] Department of Surgery, University of Western Ontario, London, ON, Canada

[4] Department of Medical Biophysics, University of Western Ontario, London, ON, Canada

[5] Department of Biochemistry, University of Western Ontario, London, ON, Canada

Introduction

Palmar fibromatosis is often referred to as Dupuytren's disease (DD) in deference to the French surgeon who was amongst the first to describe and treat this condition (Dupuytren 1834). It is a benign and heritable (Capstick et al. 2013) fibrosis that is initially evident as a nodule of myofibroblasts (Berndt et al. 1994; Bisson et al. 2003; Iwasaki et al. 1984; Magro et al. 1997; Tomasek et al. 1986) within the palmar fascia (palmar aponeurosis), a thin layer of connective tissue below the dermis in the palm. Over time, and through a poorly understood process, nodular myofibroblasts spread along the palmar fascia, secrete collagens and other extra-cellular matrix (ECM) proteins, and exert contractile forces on this collagen-enriched matrix. Contraction of these collagenous "cords" (Chiu and McFarlane 1978; Rayan 1999) result in the permanent finger contractures that characterize DD (Badalamente et al. 1996; Berndt et al. 1994; Magro et al. 1997; Tomasek et al. 1986; Tomasek et al. 1987). Depending on whether finger

Published online: 30 June 2015

contractures or the presence of palmar nodules are assessed as evidence of disease, the prevalence of DD is estimated to be between 1 and 7 % in the United States of America (Dibenedetti et al. 2012) and to be as high as 32 % in some regions of Europe (Degreef and De Smet 2012). As all of the available treatments for this fibrosis are associated with disease recurrence rates of 30 % or greater (Bulstrode et al. 2005; Foucher et al. 2003; Kan et al. 2015; Watt et al. 2012), DD is currently considered incurable.

Despite being characterized as benign, DD tissues and the primary fibroblasts derived from these tissues (DD cells) display some of the molecular characteristics of sarcomas and tumor stroma. These include, but are not limited to, increased ß-catenin levels (Howard et al. 2004; Howard et al. 2003; Varallo et al. 2003), increased expression of *FN* type III extra-domain B (ED-B) and "oncofetal" fibronectin levels, increased *POSTN* expression and periostin levels (Vi et al. 2009) and increased *IGF2* expression and insulin-like growth factor-II (IGF-II) levels (Raykha et al. 2013). We have interpreted these findings to suggest that the pathogenesis of DD and tumor/tumor stroma development may involve the activation of similar molecular pathways (Bowley et al. 2007), and that fibrosis development may represent either an alternative outcome to, or a precursor of, tumor development.

Increased *IGF2* expression and/or increased ß-catenin levels are common features of many different cancers (Alman et al. 1997; Barker and Clevers 2000; Cui 2007; de Groot et al. 2007; Heaton et al. 2013; Lu et al. 2006; Merle and Trepo 2009; Morin 1999; Shah et al. 2002; Singh et al. 1998; Tetsu and McCormick 1999) including Wilm's tumours (Fukuzawa et al. 2008; Haruta et al. 2008; Md Zin et al. 2013), a type of paediatric kidney tumour. Wilm's tumours are best known for featuring inactivating mutations of *WT1*, encoding the alternatively spliced (Charlieu et al. 1995) zinc finger transcription factor (Caricasole et al. 1996; Magro et al. 2014) and RNA splice factor (Caricasole et al. 1996; Hewitt and Saunders 1996; Kennedy et al. 1996) Wilm's tumour 1 (WT1). Despite its original identification as a tumour suppressor gene (TSG) in Wilm's tumors, *WT1* expression is frequently up regulated in other tumours where it is considered to be both oncogenic and a biomarker of tumour sub-type (Nakatsuka et al. 2006; Ohno et al. 2009; Sebire et al. 2005; Shimizu et al. 2000; Wilsher and Cheerala 2007). As *WT1* and *IGF2* are syntenic on chromosome 11p and some of their transcripts are subject to alterations in genomic imprinting in tumours (Haruta et al. 2008; Jacobs et al. 2013; Malik et al. 2000; Mitsuya et al. 1997), we were curious to see if *WT1* expression, like *IGF2* expression (Raykha et al. 2013), was dysregulated in DD. Here we report that *WT1* expression is robustly and consistently increased in DD cells relative to both syngeneic fibroblasts derived from the visibly non-fibrotic palmar fascia and allogeneic fibroblasts derived from normal palmar fascia. WT1 immunoreactivity was evident in discrete subsets of cells within fibrotic palmar fascia, but not in macroscopically unaffected palmar fascia. These findings implicate *WT1* as novel biomarker of this fibrosis and support our hypothesis that the pathogenesis of DD and tumour development share overlapping molecular characteristics.

Methods

Derivation of primary fibroblasts

Palmar fascia tissue samples were resected from patients with Dupuytren's disease (DD) and from patients undergoing carpal tunnel release (CT) during surgeries at the Roth | McFarlane Hand and Upper Limb clinic. All patients received a letter of information and signed consent forms for their tissues to be used for research purposes and the samples were collected with the approval from the University of Western Ontario Research Ethics Board for Health Sciences Research involving Human Subjects (HSREB protocol # 104888). Patient de-identification and confidentiality were achieved by assigning lab numbers to the samples prior to processing. Primary DD fibroblasts were derived from visibly fibrotic palmar fascia (DD cells), and from phenotypically unaffected adjacent palmar fascia of the same patient (PF cells), as syngeneic controls. Normal palmar fascia fibroblasts were derived from patients with no prior history of Dupuytren's Disease undergoing carpal tunnel release (CT cells) as allogeneic controls.

Real-time quantitative PCR analyses

Total RNA samples from primary DD, PF and CT cells were assessed for quality on a NanoDrop spectrophotometer ND-1000. 2 μg of high quality total RNA was reverse transcribed into cDNA first strand using the High-Capacity cDNA Archive Kit (Applied Biosystems) in accordance with the manufacturer's instructions. TaqMan gene expression assays were used to measure *WT1* mRNA levels (Hs01103751_m1) relative to the *RPLP0* endogenous control (Hs99999902_m1) using the ΔΔCt method after confirmation of parallel PCR amplification efficiencies on a Real-Time PCR ABI Prism 7500. PCR reactions were carried out under the following conditions: Initial denaturation at 95 °C for 5 min followed by 40 cycles of denaturation (95 °C for 15 s), primer annealing (60 °C for 1 min) and transcript extension (50 °C for 2 min).

Immunohistochemistry Surgically resected fibrotic (N=2) and macroscopically non-fibrotic (N=2) palmar fascia samples were resected from patients undergoing fasciectomies

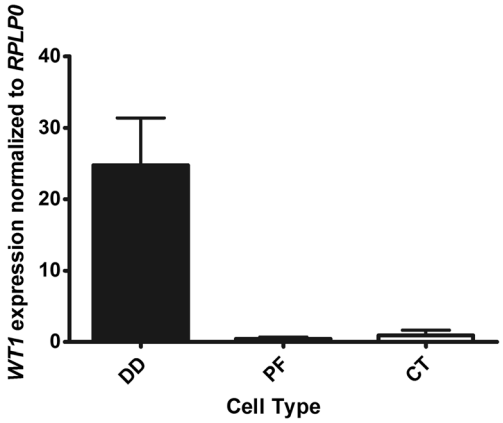

Fig. 1 Real-time PCR analyses of *WT1* expression. *WT1* expression was assessed relative to *RPLP0* (housekeeping gene) expression in primary fibroblasts (DD) derived from the fibrotic palmar fascia of patients (N=13) with DD, syngeneic fibroblasts derived from visibly non-fibrotic palmar fascia (PF) in these patients (N=13), and in allogeneic control (*CT*) fibroblasts derived from patients (N=6) with no history of DD. All samples were assessed in triplicate. Means ± SEM are shown, * indicates significant differences in *WT1* expression between DD and PF ($p<0.001$) and DD and CT ($p<0.011$) by *t*-test and between DD and both PF and CT ($p<0.01$) by ANOVA

for DD. The tissues were fixed in 10 % formalin, dehydrated, paraffin embedding and sectioned. Sections (5 μm) were dewaxed, rehydrated, and processed for antigen retrieval using standard citrate-based protocols. Sections were rinsed in PBS prior to incubation with WT1 polyclonal antibody (clone 6F-H2 in "ready to use" dilution buffer, Dako Cat# IR055). Sections were counterstained with Gills hematoxylin for 1 min and visualized by light microscopy.

Results

***WT1* expression in DD, PF and CT cells** *WT1* expression was assessed in syngeneic DD and PF cells from 13 patients and in allogeneic CT cells from 6 patients. As shown in Fig. 1, a mean increase in *WT1* expression of ≥25 fold was evident in DD cells relative to both PF cells and CT cells cultured under identical conditions in αMEM supplemented with 10 % FBS. *WT1* transcripts could not be detected in approximately 50 % (7/13) of the PF cell cultures and in 17 % (1/6) of the CT cell cultures within the 40 PCR cycle limit. In the remainder of the PF and CT cell cultures, *WT1* transcripts were detected at an average of 35 and 37 PCR cycles respectively, indicative of very low levels of *WT1* mRNA transcripts in these cells. In contrast, *WT1* expression was detected in 100 % of the DD cell cultures assessed at an average of 28 PCR cycles, and *WT1* transcripts were invariably (13/13) detected at a lower cycle of PCR cycles in the DD cells than in the PF cells derived from the same patient.

WT1 immunoreactivity in surgically resected DD tissues Paraffin-embedded fibrotic and macroscopically unaffected palmar fascia tissues were sectioned and assessed for

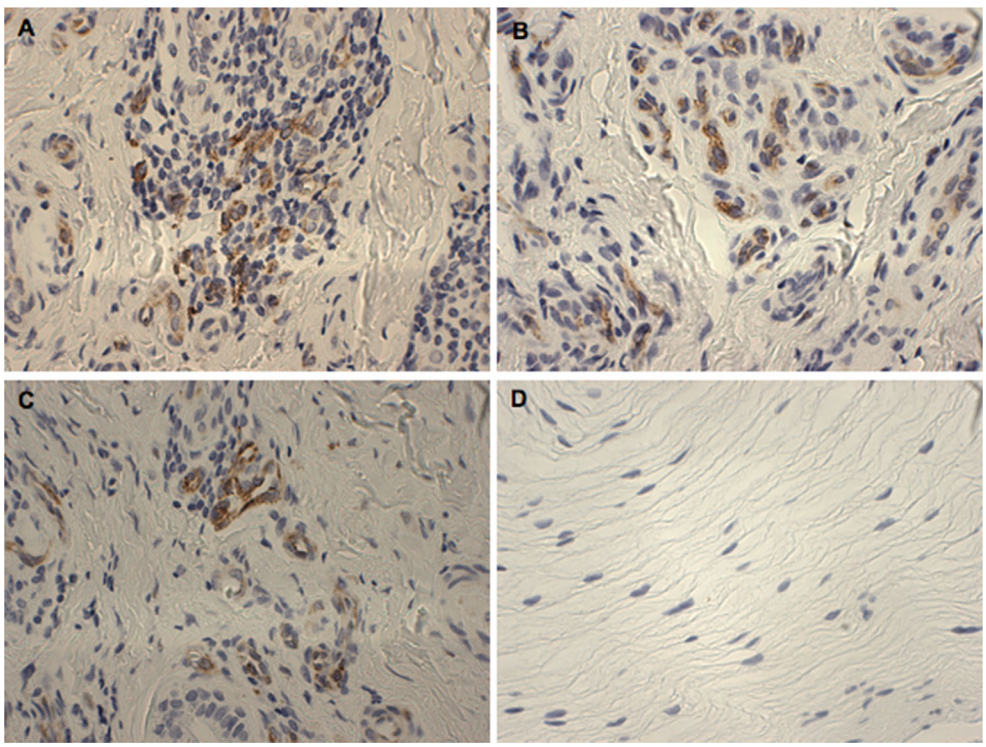

Fig. 2 WT1 immunoreactivity in fibrotic and normal palmar fascia: Paraffin embedded fibrotic (**a**, **b** and **d**) and macroscopically unaffected palmar fascia (**d**) tissues were sectioned and assessed for WT1 immunoreactivity as described in the methods. Tissues were counterstained with Gills haematoxylin to distinguish cell nuclei from palmar fascia tissue matrix

WT1 immunoreactivity as described in the methods. As shown in Fig. 2a, b and c, discrete clusters of WT1-positive cells were observed throughout the sections of fibrotic palmar fascia. In contrast, no WT1 immunoreactivity was observed in any of the macroscopically unaffected palmar fascia tissue sections assessed (Fig. 2d).

Discussion

To our knowledge, this is the first report of increased *WT1* expression and WT1 immunoreactivity in DD. The WT1-immunoreactive cells identified in DD tissues made up approximately 10 % of the total number of cells in these tissues and were typically clustered together, implying that they may represent a distinct sub-population of cells that are specific to fibrotic, but not normal, palmar fascia. The relative scarcity of WT1 positive cells in DD tissues contrasted to the consistent, high-level expression of *WT1* in primary cells derived from these tissues. It is currently unclear if WT1-positive cells are preferentially isolated during explant cultures or whether some aspect of in vitro culture enhances *WT1* expression. *WT1* gene transcripts are subject to extensive alternative splicing in other disease systems (Bickmore et al. 1992; Hewitt and Saunders 1996; Morrison et al. 2008) and the translated products of these variants may include or exclude a region encoding a Lys-Thr-Ser (KTS) tripeptide, resulting in WT1 + KTS and WT1-KTS protein isoforms (Charlieu et al. 1995; Lee and Haber 2001; Lee et al. 1999; Morrison et al. 2006). The WT1-KTS isoform has been reported to localize to the nucleus, bind DNA and function as a zinc-finger transcription factor to activate or repress gene transcription, whereas the WT1 + KTS isoform is proposed to interact with factors that regulate RNA splicing in the cytoplasm (Morrison et al. 2006). The nuclear or cytoplasmic localization of WT1 varies between tumor types and is used for tumor characterization (Hecht et al. 2002; Magro et al. 2014; Nakatsuka et al. 2006; Sebire et al. 2005), however it is unclear if the cellular location of WT1 immunoreactivity strictly correlates with the relative abundance of + KTS and -KTS isoforms. While WT1 immunoreactivity appeared to be mostly localized to the cytoplasm of cells in fibrotic palmar fascia tissues, further analyses will be required to confirm this observation and any correlation with WT1 isoform expression.

IGF2 and *WT1* are syntenic on the short arm of chromosome 11, at 11p15.5 and 11p13 respectively, and each express a subset of transcripts that are subject to genomic imprinting, or parent-of origin-specific gene expression, in various tissues. Loss of *IGF2* and *WT1* imprinting in tumors typically results in up regulated expression levels (Brown et al. 2008; Jacobs et al. 2013), and our recent unpublished findings suggest that *IGF2* imprinting may be lost in a subset of patients with DD. As both *IGF2* and *WT1* expression levels are up regulated in DD cells, we will include *WT1* in these ongoing studies to determine if abnormal epigenetic regulation of expression contributes to the increased *IGF2* and *WT1* transcript levels in this fibrosis.

Depletion of WT1 levels in idiopathic pulmonary fibrosis has been reported to inhibit myofibroblast formation (Karki et al. 2015) and increased *WT1* expression in DD myofibroblasts may imply a similar role for WT1 in their development. If WT1 depletion in DD is found to inhibit myofibroblast development, it may be feasible to cross-purpose the WT1 peptide-based immuno-therapies currently under clinical investigation as treatments for a variety of cancers (Dohi et al. 2011; Dubrovsky et al. 2014; Elmaagacli et al. 2005; Nishida et al. 2014; Oka et al. 2002; Oka et al. 2006; Shirakata et al. 2012) as anti-fibrotic interventions. While the efficacy of this novel approach is yet to be clearly demonstrated, the potential to attenuate fibrosis-associated myofibroblast development by immunizing patients with WT1 peptides is intriguing and may be worthy of further investigation.

References

Alman BA, Li C, Pajerski ME, Diaz-Cano S, Wolfe HJ (1997) Increased beta-catenin protein and somatic APC mutations in sporadic aggressive fibromatoses (desmoid tumors). Am J Pathol 151:329–334

Badalamente MA, Sampson SP, Hurst LC, Dowd A, Miyasaka K (1996) The role of transforming growth factor beta in Dupuytren's disease. J Hand Surg [Am] 21:210–215

Barker N, Clevers H (2000) Catenins, Wnt signaling and cancer. Bioessays 22:961–965

Berndt A, Kosmehl H, Katenkamp D, Tauchmann V (1994) Appearance of the myofibroblastic phenotype in Dupuytren's disease is associated with a fibronectin, laminin, collagen type IV and tenascin extracellular matrix. Pathobiology 62:55–58

Bickmore WA, Oghene K, Little MH, Seawright A, van Heyningen V, Hastie ND (1992) Modulation of DNA binding specificity by alternative splicing of the Wilms tumor wt1 gene transcript. Science 257: 235–237

Bisson MA, McGrouther DA, Mudera V, Grobbelaar AO (2003) The different characteristics of Dupuytren's disease fibroblasts derived from either nodule or cord: expression of alpha-smooth muscle actin and the response to stimulation by TGF-beta1. J Hand Surg (Br) 28: 351–356

Bowley E, O'Gorman DB, Gan BS (2007) Beta-catenin signaling in fibroproliferative disease. J Surg Res 138:141–150

Brown KW, Power F, Moore B, Charles AK, Malik KT (2008) Frequency and timing of loss of imprinting at 11p13 and 11p15 in Wilms' tumor development. Mol Cancer Res 6:1114–1123

Bulstrode NW, Jemec B, Smith PJ (2005) The complications of Dupuytren's contracture surgery. J Hand Surg [Am] 30:1021–1025

Capstick R, Bragg T, Giele H Furniss D (2013) Sibling recurrence risk in Dupuytren's disease. J Hand Surg Eur 38:424–9

Caricasole A, Duarte A, Larsson SH, Hastie ND, Little M, Holmes G, Todorov I, Ward A (1996) RNA binding by the Wilms tumor suppressor zinc finger proteins. Proc Natl Acad Sci U S A 93:7562–7566

Charlieu JP, Larsson S, Miyagawa K, van Heyningen V, Hastie ND (1995) Does the Wilms' tumour suppressor gene, WT1, play roles in both splicing and transcription? J Cell Sci Suppl 19:95–99

Chiu HF, McFarlane RM (1978) Pathogenesis of Dupuytren's contracture: a correlative clinical- pathological study. J Hand Surg [Am] 3: 1–10

Cui H (2007) Loss of imprinting of IGF2 as an epigenetic marker for the risk of human cancer. Dis Markers 23:105–112

de Groot JW, Rikhof B, van Doorn J, Bilo HJ, Alleman MA, Honkoop AH, van der Graaf WT (2007) Non-islet cell tumour-induced hypoglycaemia: a review of the literature including two new cases. Endocr Relat Cancer 14:979–993

Degreef I, De Smet L (2012) A high prevalence of Dupuytren's disease in Flanders. Acta Orthop Belg 76:316–320

Dibenedetti DB, Nguyen D, Zografos L, Ziemiecki R, Zhou X (2012) Prevalence, incidence, and treatments of Dupuytren's disease in the United States: results from a population-based study. Hand (N Y) 6: 149–158

Dohi S, Ohno S, Ohno Y, Takakura M, Kyo S, Soma G, Sugiyama H, Inoue M (2011) WT1 peptide vaccine stabilized intractable ovarian cancer patient for one year: a case report. Anticancer Res 31:2441–2445

Dubrovsky L, Pankov D, Brea EJ, Dao T, Scott A, Yan S, O'Reilly RJ, Liu C, Scheinberg DA (2014) A TCR-mimic antibody to WT1 bypasses tyrosine kinase inhibitor resistance in human BCR-ABL+ leukemias. Blood 123:3296–3304

Dupuytren G (1834) Permanent retraction of the fingers, produced by an affection of the palmar fascia. Lancet 2:222–225

Elmaagacli AH, Koldehoff M, Peceny R, Klein-Hitpass L, Ottinger H, Beelen DW, Opalka B (2005) WT1 and BCR-ABL specific small interfering RNA have additive effects in the induction of apoptosis in leukemic cells. Haematologica 90:326–334

Foucher G, Medina J, Navarro R (2003) Percutaneous needle aponeurotomy: complications and results. J Hand Surg (Br) 28: 427–431

Fukuzawa R, Anaka MR, Heathcott RW, McNoe LA, Morison IM, Perlman EJ, Reeve AE (2008) Wilms tumour histology is determined by distinct types of precursor lesions and not epigenetic changes. J Pathol 215:377–387

Haruta M, Arai Y, Sugawara W, Watanabe N, Honda S, Ohshima J, Soejima H, Nakadate H, Okita H, Hata J et al (2008) Duplication of paternal IGF2 or loss of maternal IGF2 imprinting occurs in half of Wilms tumors with various structural WT1 abnormalities. Genes Chromosome Cancer 47:712–727

Heaton JH, Wood MA, Kim AC, Lima LO, Barlaskar FM, Almeida MQ, Fragoso MC, Kuick R, Lerario AM, Simon DP et al (2013) Progression to adrenocortical tumorigenesis in mice and humans through insulin-like growth factor 2 and beta-catenin. Am J Pathol 181:1017–1033

Hecht JL, Lee BH, Pinkus JL, Pinkus GS (2002) The value of Wilms tumor susceptibility gene 1 in cytologic preparations as a marker for malignant mesothelioma. Cancer 96:105–109

Hewitt SM, Saunders GF (1996) Differentially spliced exon 5 of the Wilms' tumor gene WT1 modifies gene function. Anticancer Res 16:621–626

Howard JC, Varallo VM, Ross DC, Roth JH, Faber KJ, Alman B, Gan BS (2003) Elevated levels of beta-catenin and fibronectin in three-dimensional collagen cultures of Dupuytren's disease cells are regulated by tension in vitro. BMC Musculoskelet Disord 4:16

Howard JC, Varallo VM, Ross DC, Faber KJ, Roth JH, Seney S, Gan BS (2004) Wound healing-associated proteins Hsp47 and fibronectin are elevated in Dupuytren's contracture. J Surg Res 117:232–238

Iwasaki H, Muller H, Stutte HJ, Brennscheidt U (1984) Palmar fibromatosis (Dupuytren's contracture). Ultrastructural and enzyme histochemical studies of 43 cases. Virchows Arch A Pathol Anat Histopathol 405:41–53

Jacobs DI, Mao Y, Fu A, Kelly WK, Zhu Y (2013) Dysregulated methylation at imprinted genes in prostate tumor tissue detected by methylation microarray. BMC Urol 13:37

Kan HJ, Verrijp FW, Huisstede BM, Hovius SE, van Nieuwenhoven CA, Selles RW (2015) The consequences of different definitions for recurrence of Dupuytren's disease. J Plast Reconstr Aesthet Surg 66:95–103

Karki S, Surolia R, Hock TD, Guroji P, Zolak JS, Duggal R, Ye T, Thannickal VJ, Antony VB (2015) Wilms' tumor 1 (Wt1) regulates pleural mesothelial cell plasticity and transition into myofibroblasts in idiopathic pulmonary fibrosis. Faseb J 28:1122–1131

Kennedy D, Ramsdale T, Mattick J, Little M (1996) An RNA recognition motif in Wilms' tumour protein (WT1) revealed by structural modelling. Nat Genet 12:329–331

Lee SB, Haber DA (2001) Wilms tumor and the WT1 gene. Exp Cell Res 264:74–99

Lee SB, Huang K, Palmer R, Truong VB, Herzlinger D, Kolquist KA, Wong J, Paulding C, Yoon SK, Gerald W et al (1999) The Wilms tumor suppressor WT1 encodes a transcriptional activator of amphiregulin. Cell 98:663–673

Lu L, Katsaros D, Wiley A, Rigault de la Longrais IA, Puopolo M, Schwartz P, Yu H (2006) Promoter-specific transcription of insulin-like growth factor-II in epithelial ovarian cancer. Gynecol Oncol 103:990–995

Magro G, Salvatorelli L, Vecchio GM, Musumeci G, Rita A, Parenti R (2014) Cytoplasmic expression of Wilms tumor transcription factor-1 (WT1): a useful immunomarker for young-type fibromatoses and infantile fibrosarcoma. Acta Histochem 116:1134–40

Magro G, Fraggetta F, Colombatti A, Lanzafame S (1997) Myofibroblasts and extracellular matrix glycoproteins in palmar fibromatosis. Gen Diagn Pathol 142:185–190

Malik K, Salpekar A, Hancock A, Moorwood K, Jackson S, Charles A, Brown KW (2000) Identification of differential methylation of the WT1 antisense regulatory region and relaxation of imprinting in Wilms' tumor. Cancer Res 60:2356–2360

Md Zin R, Murch A, Charles A (2013) Pathology, genetics and cytogenetics of Wilms' tumour. Pathology 43:302–312

Merle P, Trepo C (2009) Molecular mechanisms underlying hepatocellular carcinoma. Viruses 1:852–872

Mitsuya K, Sui H, Meguro M, Kugoh H, Jinno Y, Niikawa N, Oshimura M (1997) Paternal expression of WT1 in human fibroblasts and lymphocytes. Hum Mol Genet 6:2243–2246

Morin PJ (1999) beta-catenin signaling and cancer. Bioessays 21:1021–1030

Morrison AA, Venables JP, Dellaire G, Ladomery MR (2006) The Wilms tumour suppressor protein WT1 (+KTS isoform) binds alpha-actinin 1 mRNA via its zinc-finger domain. Biochem Cell Biol 84:789–798

Morrison AA, Viney RL, Ladomery MR (2008) The post-transcriptional roles of WT1, a multifunctional zinc-finger protein. Biochim Biophys Acta 1785:55–62

Nakatsuka S, Oji Y, Horiuchi T, Kanda T, Kitagawa M, Takeuchi T, Kawano K, Kuwae Y, Yamauchi A, Okumura M et al (2006) Immunohistochemical detection of WT1 protein in a variety of cancer cells. Mod Pathol 19:804–814

Nishida S, Koido S, Takeda Y, Homma S, Komita H, Takahara A, Morita S, Ito T, Morimoto S, Hara K et al (2014) Wilms tumor gene (WT1) peptide-based cancer vaccine combined with gemcitabine for patients with advanced pancreatic cancer. J Immunother 37:105–14

Ohno S, Dohi S, Ohno Y, Kyo S, Sugiyama H, Suzuki N, Inoue M (2009) Immunohistochemical detection of WT1 protein in endometrial cancer. Anticancer Res 29:1691–1695

Oka Y, Tsuboi A, Elisseeva OA, Udaka K, Sugiyama H (2002) WT1 as a novel target antigen for cancer immunotherapy. Curr Cancer Drug Targets 2:45–54

Oka Y, Tsuboi A, Kawakami M, Elisseeva OA, Nakajima H, Udaka K, Kawase I, Oji Y, Sugiyama H (2006) Development of WT1 peptide

cancer vaccine against hematopoietic malignancies and solid cancers. Curr Med Chem 13:2345–2352

Rayan GM (1999) Clinical presentation and types of Dupuytren's disease. Hand Clin 15(87–96):vii

Raykha C, Crawford J, Gan BS, Fu P, Bach LA, O'Gorman DB (2013) IGF-II and IGFBP-6 regulate cellular contractility and proliferation in Dupuytren's disease. Biochim Biophys Acta 1832:1511–1519

Sebire NJ, Gibson S, Rampling D, Williams S, Malone M, Ramsay AD (2005) Immunohistochemical findings in embryonal small round cell tumors with molecular diagnostic confirmation. Appl Immunohistochem Mol Morphol 13:1–5

Shah S, Pishvaian MJ, Easwaran V, Brown PH, Byers SW (2002) The role of cadherin, beta-catenin, and AP-1 in retinoid-regulated carcinoma cell differentiation and proliferation. J Biol Chem 277:25313–25322

Shimizu M, Toki T, Takagi Y, Konishi I, Fujii S (2000) Immunohistochemical detection of the Wilms' tumor gene (WT1) in epithelial ovarian tumors. Int J Gynecol Pathol 19:158–163

Shirakata T, Oka Y, Nishida S, Hosen N, Tsuboi A, Oji Y, Murao A, Tanaka H, Nakatsuka S, Inohara H et al (2012) WT1 peptide therapy for a patient with chemotherapy-resistant salivary gland cancer. Anticancer Res 32:1081–1085

Singh P, Dai B, Given RL, Lu X, Holthuizen PE (1998) Differential activation of IGF-II promoters P3 and P4 in Caco-2 cells during growth and differentiation. Gastroenterology 114:1221–1229

Tetsu O, McCormick F (1999) Beta-catenin regulates expression of cyclin D1 in colon carcinoma cells. Nature 398:422–426

Tomasek JJ, Schultz RJ, Episalla CW, Newman SA (1986) The cytoskeleton and extracellular matrix of the Dupuytren's disease "myofibroblast": an immunofluorescence study of a nonmuscle cell type. J Hand Surg [Am] 11:365–371

Tomasek JJ, Schultz RJ, Haaksma CJ (1987) Extracellular matrix-cytoskeletal connections at the surface of the specialized contractile fibroblast (myofibroblast) in Dupuytren disease. J Bone Joint Surg Am 69:1400–1407

Varallo VM, Gan BS, Seney S, Ross DC, Roth JH, Richards RS, McFarlane RM, Alman B, Howard JC (2003) Beta-catenin expression in Dupuytren's disease: potential role for cell-matrix interactions in modulating beta-catenin levels in vivo and in vitro. Oncogene 22:3680–3684

Vi L, Feng L, Zhu RD, Wu Y, Satish L, Gan BS, O'Gorman DB (2009) Periostin differentially induces proliferation, contraction and apoptosis of primary Dupuytren's disease and adjacent palmar fascia cells. Exp Cell Res 315(20):3574–3586

Watt AJ, Curtin CM, Hentz VR (2012) Collagenase injection as nonsurgical treatment of Dupuytren's disease: 8-year follow-up. J Hand Surg Am 35:534–9, 539 e1

Wilsher M, Cheerala B (2007) WT1 as a complementary marker of malignant melanoma: an immunohistochemical study of whole sections. Histopathology 51:605–610